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Zooplankton Studies at Ocean Weather Station "P" in the Northeast Pacific Ocean[1]

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ABSTRACT

Concentrations of zooplankton observed at Station "P" (50° N.L., 145° W.L.,) are less than those in the Northwest Pacific, the Bering Sea, British Columbia coastal waters and the Labrador Sea; about equal to those at Station "M" in the Norwegian Sea; and greater than those in the central Equatorial Pacific and the Sargasso Sea. Zooplankton abundance at Station "P" appears representative of that in a wide area of the central Gulf of Alaska. A vertical distribution of zooplankton characterized by maxima of concentration from 0–100 metres and from 200–500 m was observed both day and night and in all seasons. Daily means of concentration of surface zooplankton ranged from about 20 g per 1000 m³ in winter to about 150 in summer. A small autumn maximum was observed. A similar seasonal cycle of abundance occurred down to depths of about 200 m. Below 200 m the amplitude of the seasonal cycle tended to decrease with depth. Vertical hauls captured mainly copepods all year round. Horizontal surface tows revealed a marked seasonal cycle in taxonomic composition. A pronounced diurnal variation in the concentration of surface zooplankton was observed and showed the major features of typical diurnal vertical migration. Night catches of vertical hauls exceeded day catches.

A. INTRODUCTION

OCEAN WEATHER STATION "P" is located at Latitude 50° N, Longitude 145° W about 500 miles west of the north end of Vancouver Island (Fig. 1). The station is manned by two Canadian ships alternately, each occupying the position for 6 weeks, and being relieved on station by the other.
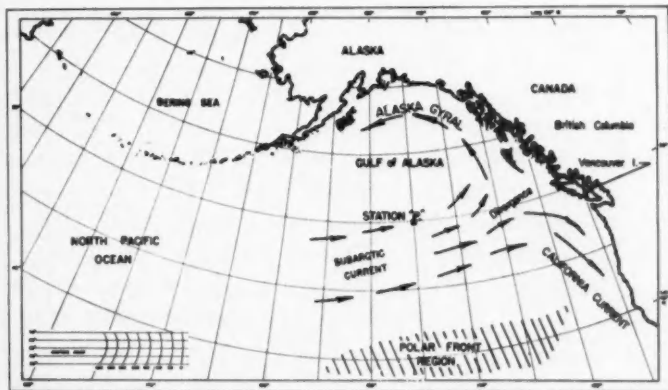
FIG. 1.   Chart showing position of station "P".

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Since 1952 bathythermograph lowerings have been made twice daily on station, and approximately every 30 miles en route to and from the station. In August 1956, the C.G.S. *St. Catharines* was equipped for carrying out a more detailed program of oceanographic observations. The data are published annually (Pacific Oceanographic Group, 1957b, 1958).

In the present study some of the major features of the zooplankton data obtained during the first year and a half of the detailed program are discussed.

B. INTRODUCTION TO THE PHYSICAL OCEANOGRAPHY

Station "P" lies within the subarctic water mass of the North Pacific Ocean (Sverdrup *et al.*, 1942). The subarctic water mass may be characterized by its vertical salinity structure (Fig. 2) which consists of 3 layers (Tully and Dodimead,
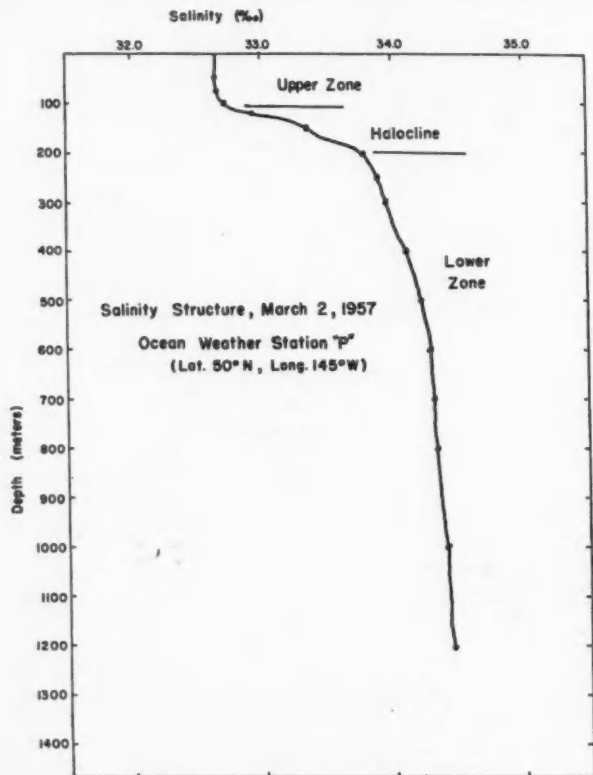
Fig. 2. Typical salinity structure in the subarctic water mass of the Northeast Pacific.

MS, 1957): an almost homogeneous upper layer having relatively low salinities; a permanent halocline with a salinity change of about 1‰ and which marks the limit of seasonal variation; and below 200 m, a deep zone in which salinity gradually increases with depth.

Doe (1955) described 3 oceanographic regions (Fig. 3) in the relatively homogeneous subarctic area of the Northeast Pacific: a continuous "coastal" region having surface salinities less than 32.5‰; an "offshore" region with surface salinities averaging about 32.6‰; and a "midgulf" region with higher salinities than the surrounding "offshore" water.
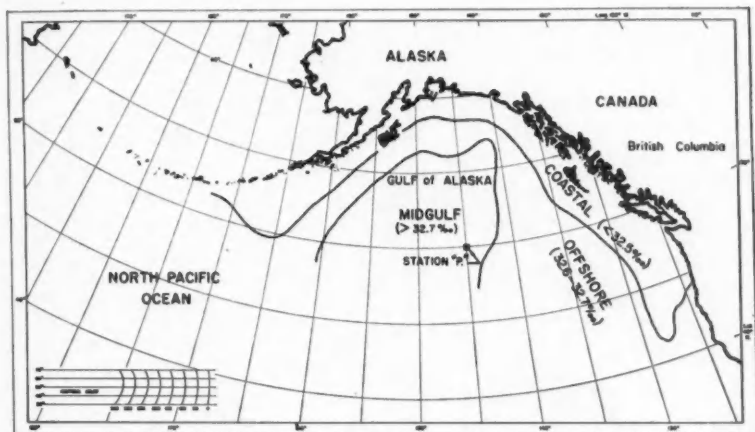
FIG. 3.   Oceanographic regions in the Northeast Pacific (after Doe, 1955).

The three regions described by Doe (1955) can be identified in the plots of salinity data (Fig. 4) presented by Tully and Dodimead (1957) and Dodimead (1958).   The "midgulf" water occupies the northwest part of the Gulf of Alaska and the low salinity "coastal" water lies along the British Columbia and Alaska coastline.   The "offshore" region, with salinities of about 32.6‰, lies between the "midgulf" and "coastal" regions and is bounded on the south by the Polar Front (see below).   Station "P" appears to occupy a position near the diffuse boundary between "midgulf" and "offshore" water.

Temperature-salinity relationships also suggest that station "P" lies near the boundary region between "midgulf" and "offshore" waters.   The distribution of some of these relationships, as arbitrarily defined by Tully and Dodimead (1957), is presented in Fig. 5.   Examination of the figure suggests that relationships 10 and 11 correspond to Doe's "midgulf" and "offshore" waters respectively.
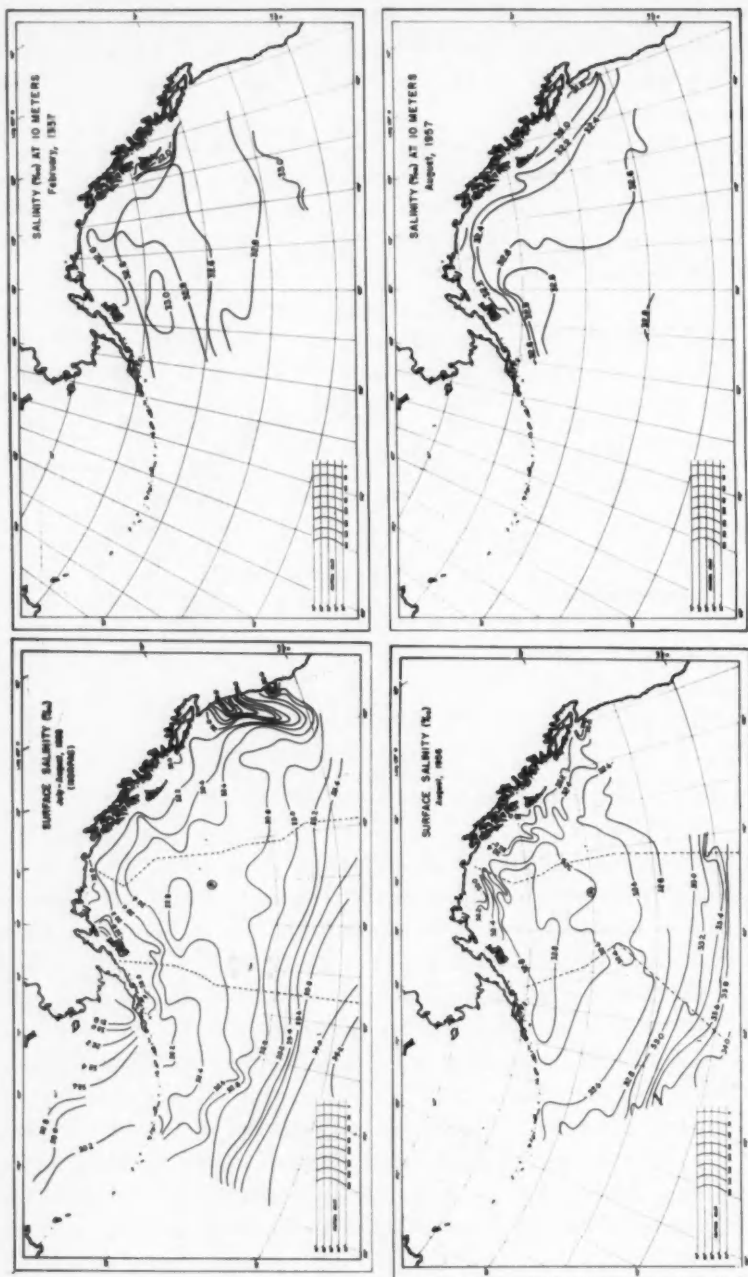
FIG. 4. Distributions of salinity in the Northeast Pacific (from Tully and Dodimead, MS, 1957; and Dodimead, MS, 1958).
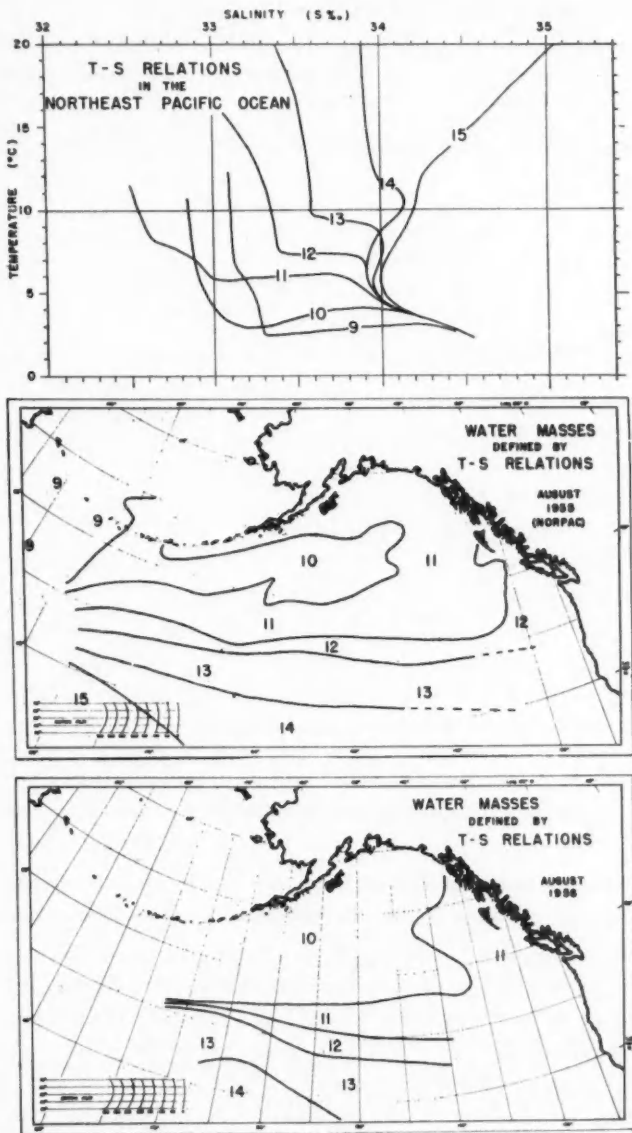
FIG. 5.   Temperature–salinity relationships in the Northeast Pacific
(From Tully and Dodimead, MS, 1957).

It can be seen in Fig. 6 that temperature–salinity relationships observed at station "P" are intermediate between these two types.

The Subarctic Current (Sverdrup *et al.*, 1942) enters the area surrounding station "P" from a westerly direction and diverges east of the station to from
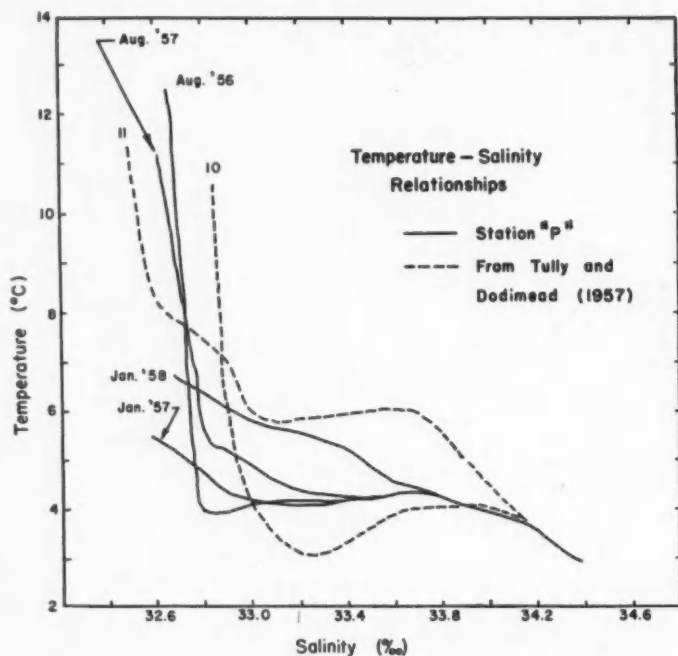
FIG. 6. Temperature–salinity relationships at station "P".

the south-flowing California Current and the counter-clockwise Alaska Gyral (Fig. 1). The currents near station "P" are slow, from 1 to 2 sea miles per day (Dodimead, 1958).

South of station "P" gradients of rising salinity (Fig. 4) and temperature (Fig. 7) increase to form the Polar Front (Fig. 1) (Tully and Dodimead, 1957).

In summary, station "P" might be considered to lie in an oceanographic area bounded on the northwest by the centre of the Alaska Gyral ("midgulf" water), by the coastal region to the northeast, by the divergence of the Subarctic Current to the east, and by the Polar Front to the south. Within this area, currents are sluggish and winter mixing is limited approximately to the upper 120 m of depth.
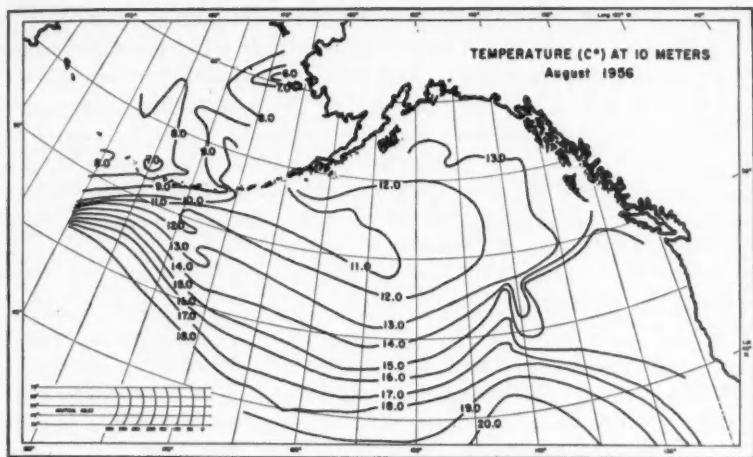
Fig. 7. Distribution of temperature in the Northeast Pacific (from Tully and Dodimead, MS, 1957).

C. METHODS

1. SAMPLING TECHNIQUES

The plankton samples studied here were obtained during alternate 6-week periods beginning August 26, 1956 and ending January 23, 1958.   (Table I, Fig. 8).

All samples were taken with a standard "NorPac" net (Reid, 1956), 45 cm in diameter, 180 cm long, and made of nylon netting of 0.33 mm aperture width (equivalent to No. 3 silk bolting cloth).

Three series of observations were made:

1. Nets were hauled vertically from a depth of 150 m to the surface (August, 1956 to January, 1958).

2. Nets were towed horizontally at the surface, at 2-hour intervals, throughout 24-hour periods (December, 1956 to January, 1958).

3. Nets were hauled vertically from a series of depths (50, 100, 150, 200, 300, 500 and occasionally 1000 m) to the surface (March, 1957 to January, 1958).

The nets were not metered.   However, the results of 150-metre vertical hauls from the Bering Sea (Hokkaido University, 1957) taken under similar operating conditions with metered "NorPac" nets, were used to estimate the efficiency of filtration.   These data suggest that on the average the effect of the netting and clogging by organisms in reducing the amount of water entering the net is approximately balanced by the increase in the distance towed resulting

from ship's drift.   An opening 45 cm in diameter will pass 24 m³ of water when hauled a distance of 150 m.   The Bering Sea hauls filtered a mean volume of 25 ± 7 m³, close to the theoretical.   It is therefore assumed that the nets used in vertical hauls at station "P" operated at 100% of nominal efficiency.

Horizontal surface tows were made at a speed of about 2 knots (1 m/sec) for 30 minutes.   The net was towed with the opening approximately half submerged, thus reducing the ratio between the volume of water entering the net and the area of netting available for filtering.   In calculating the results of surface tows the filtration was assumed to be 100% efficient.

2. TREATMENT OF SAMPLES

Fish and organisms exceeding $1\frac{1}{2}$ inches (38 mm) in length were removed from the samples before analysis.   The percentage of the total wet weight formed by each major phylogenetic constituent was estimated by microscopic examination.   Wet weights were determined after draining the samples in No. 20 silk bolting cloth (aperture 0.076 mm) and drying them for 10–15 minutes between layers of paper towelling.   The percentages obtained from the microscopic examination were then used to calculate the weights of the constituents.   The calculated weights of such forms as medusae, phytoplankton and detritus were subtracted from the total to give the weight of "edible" zooplankton.   Concentrations are expressed in grams (wet weight) per 1000 m³ of water.

D. RESULTS AND DISCUSSION

1. LEVEL OF ABUNDANCE

Concentrations of zooplankton observed at station "P" ranged from about 0.3 to over 800 g per 1000 m³.   Mean concentrations of zooplankton and their ranges are presented in Table I.   The means were calculated from data presented in Fig. 8, 9, 10, 11, 12 and 13.

Zooplankton concentrations at station "P" are compared with those in other

TABLE I. Mean concentrations of zooplankton observed at ocean weather station "P" (Latitude 50° N, Longitude 145° W).

Type of sample	Sampling period	No. of samples	Mean concent'n (g/1000 m³)	Range (g/1000 m³)
Surface tow	Dec. 56–Jan. 58	150	54	0–800
0–50 m vertical haul	Mar. 57–Jan. 58	27	48	7–327
0–100 m " "	Mar. 57–Jan. 58	27	48	1–294
0–150 m " "	Aug. 56–Aug. 57	61	31	0–200
0–150 m " "	Dec. 56–Dec. 57	69	29	0–200
0–200 m " "	Mar. 57–Jan. 58	27	37	3–215
0–300 m " "	Mar. 57–Jan. 58	27	39	8–136
0–500 m " "	Mar. 57–Jan. 58	26	40	6–118
0–1000 m " "	Apr. 57–Jan. 58	11	31	17–59
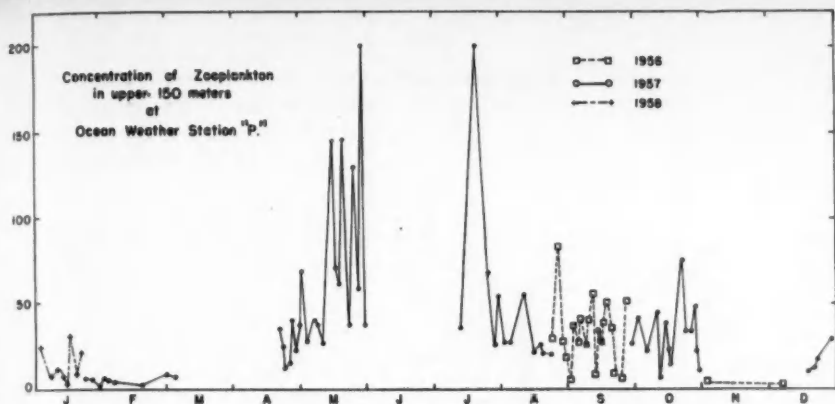
FIG. 8. Concentrations of zooplankton in the upper 150 m at Station "P".
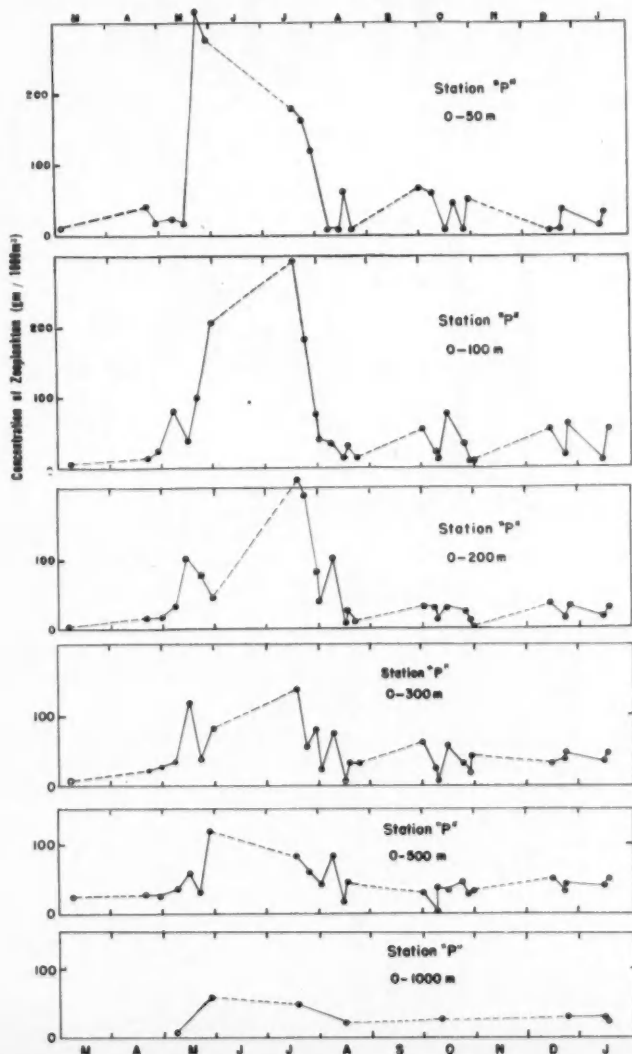
FIG. 9. Concentration of zooplankton from successive depths to the surface at Station "P".
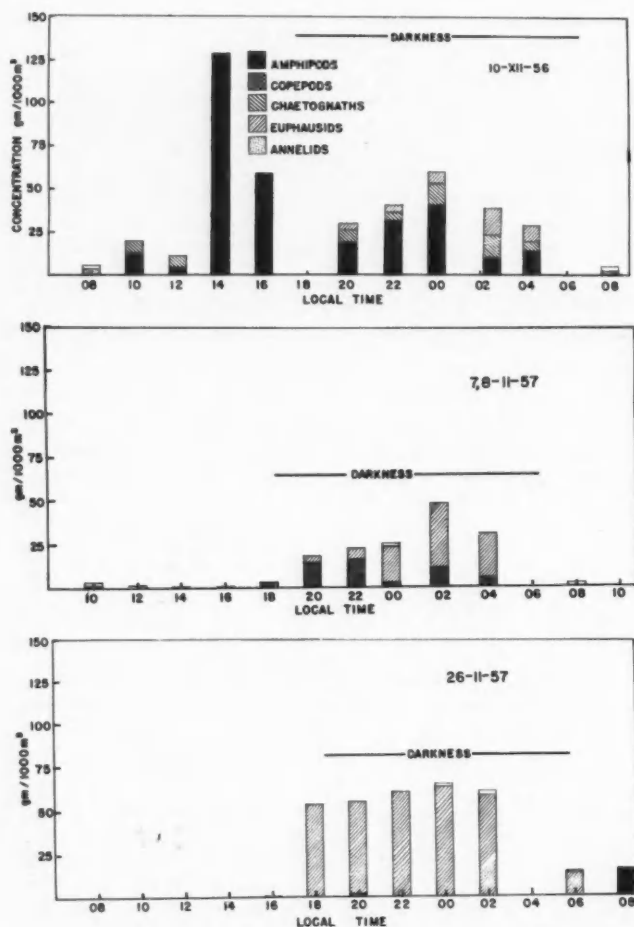
FIG. 10.   The diurnal variation of surface zooplankton at station "P",
Dec. 10, 1956, Feb. 7 and 8, 1957, and Feb. 26, 1957.
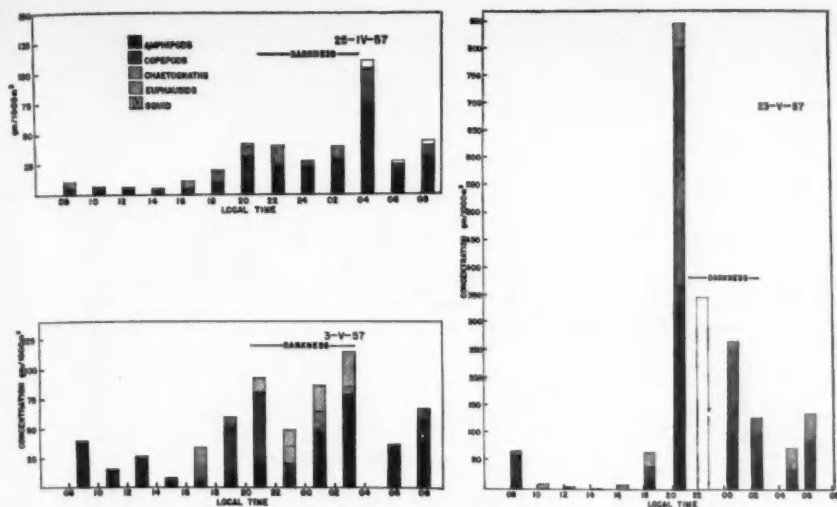
FIG. 11. The diurnal variation of surface zooplankton at station "P", April 25, 1957, May 3 and 23, 1957.
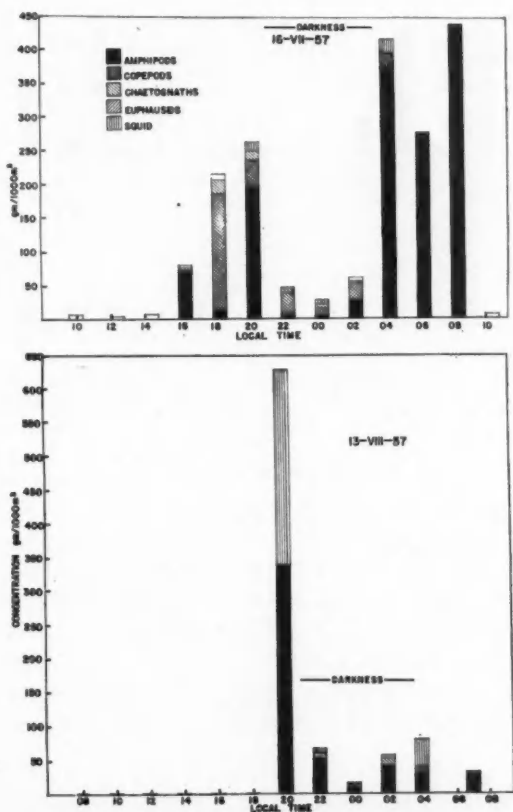
FIG. 12. The diurnal variation of surface zooplankton at station "P", July 16, 1957, and Aug. 13, 1957.
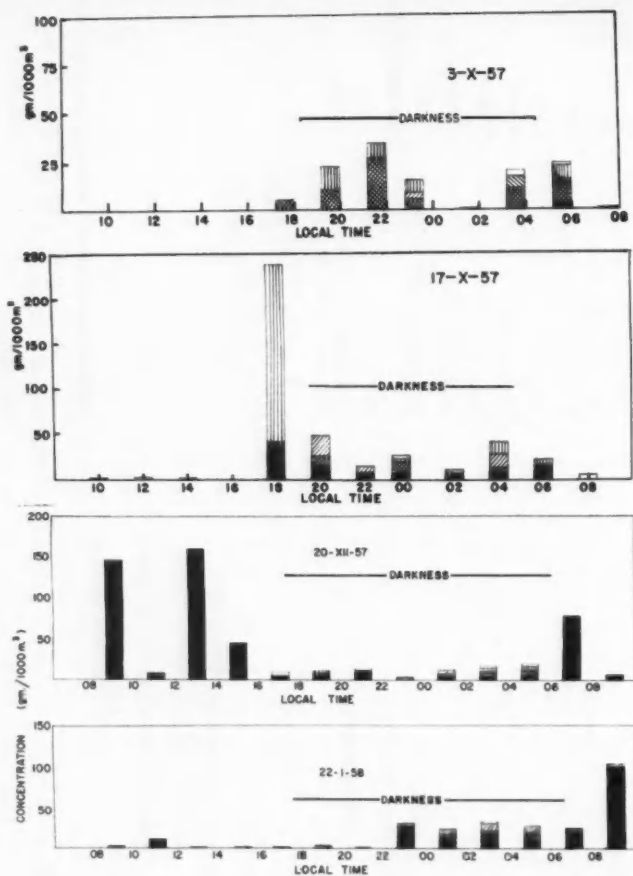
FIG. 13. The diurnal variation of surface zooplankton at station "P", Oct. 3 and 17, 1957, Dec. 20, 1957, and Jan. 22, 1958.

seas in Table II. The ratios can be only very approximate. Some of the data are separated by periods of years, were obtained with different nets and techniques, and recorded in different units. Concentrations expressed in terms of unit volume were multiplied by a factor of 0.62, determined from Bering Sea data (Hokkaido University, 1957), in order to obtain weights. Catches expressed in units per net haul were converted to weight per 1000 m³ of sea water by assuming that the nets operated at 100% efficiency.

According to the information in Table II, concentrations of zooplankton at station "P" are lower than those from the Northwest Pacific, the Bering Sea,

TABLE II. Comparison of zooplankton concentrations at ocean weather station "P" (Latitude 50° N, Longitude 145° W) with concentrations from other seas.

Sea area	Author	Date	Sampling method	Concentration (g/1000 m^2)	Conc. at "P" (g/1000 m^3)	Ratio Stn. "P" to other area
NW Pacific	Bogorov and Vinogradov, 1955	Summer	100 m vertical haul	100–500	12–294	0.12–0.59
Bering Sea	Hokkaido Univ. 1957	Aug. 1956	150 m vertical haul	200	42	0.21
Labrador Sea	Kielhorn, 1952	Annual	Surface (night)	342	85	0.25
B.C. Coast	P.O.G. unpublished	April, May 1957	150 m vertical haul	185	70	0.38
Norwegian Sea	Wiborg, 1954	Annual	100 m vertical haul	50	48	0.98
Central Equatorial Pacific	King and Hida, 1957	Annual	24-hour surface tows	35	54	1.54
Central Equatorial Pacific	King and Hida, 1957	Annual	200 m oblique haul	18	30	1.67
Sargasso Sea	Riley et al., 1949	Annual	100 m vertical (Crustacea only)	17	40	2.35
Sargasso Sea	Fish, 1956	Annual	Surface (night)	10	85	8.5

the Labrador Sea, and British Columbia coastal waters; they are about equal to concentrations at ocean weather station "M" in the Norwegian Sea; and are greater than those from the central Equatorial Pacific and the Sargasso Sea.

The production of zooplankton is usually expected to be high in regions where physical processes tend to enrich the euphotic layer of the ocean with the nutrients necessary for the production of phytoplankton, the food of the zooplankton (Laevastu, 1957). Such regions may be found near areas of divergence between currents, along coasts where the action of wind-induced currents result in upwelling, and in the center of cyclonic gyrals in the northern hemisphere. Areas in which currents and bottom configuration result in turbulence, and regions with intense winter overturn and mixing may also be productive.

Standing crops of zooplankton are also commonly found to be higher in or near such regions (Laevastu, 1957) but this need not be so, since areas of high production may have low standing crops of zooplankton if predation by fish is also high. High standing crops may also be found in regions where convergences, in the center of gyrals or between currents, physically concentrate zooplankton (Laevastu, 1957).

At station "P" the currents are sluggish, the water is deep (approximately 4000 m), no strong convergences or divergences are present, the center of the nearest gyral is some 600 miles away and the stability imparted to the water column by the permanent halocline limits winter overturn and mixing to the upper 120 m. Thus, according to the physical criteria cited above, both the production and standing crop of zooplankton at station "P" should be relatively low. Although there are no data on production of zooplankton at station "P", the comparisons in Table II suggest that the standing crops are as might be expected.

The regions, shown in Table II, that have standing crops higher than those at station "P", all display one or more of the mechanisms described above as resulting in high production and standing crops of zooplankton. Convergences and winter overturn occur in the Northwest Pacific (Sverdrup et al., 1942). The data from the Labrador Sea were obtained at ocean weather station "B", near the center of a large gyral and in an area with intense winter overturn (Kielhorn, 1952). Convergences (Laevastu, 1957), winter mixing, and bottom effects act in the Bering Sea. Along the British Columbia coastline wind-induced upwelling raises deep water to shallower levels (Doe, 1955).

However both the Norwegian Sea, with zooplankton concentrations about equal to those at station "P", and the central Equatorial Pacific, with less zooplankton than station "P", are also endowed with enriching physical mechanisms. Ocean weather station "M", at which the Norwegian Sea data were obtained, lies near the center of a gyral in a region where winter mixing is intense. Wiborg (1955) states that the Norwegian Sea is a productive region supporting rich

fisheries. The central Equatorial Pacific, with a marked divergence and convergence, is also believed to be a productive region (e.g., King and Hida, 1957). Since station "P" has standing crops of zooplankton equal to or greater than the above regions, it might be argued that "P" too, contrary to the earlier suggestion in this report, must lie in a productive region.

The contradiction may arise partly because of the difficulty of making valid comparisons amongst data not designed for the purpose. Also, the physical criteria used are incomplete and are valid only in a general way. The strength and duration of the enriching mechanisms, light intensities, effects of turbulence, rate of regeneration of nutrients, and other factors may also influence basic productivity, and hence production and standing crops of zooplankton. And it must be again emphasized that standing crops are determined by *consumption* as well as production. Direct measurements of basic production and of more members of the food chain are required.

Concentrations of zooplankton observed in the Northeast Pacific during recent oceanographic surveys are presented in Fig. 14. Mean concentrations of zooplankton observed at station "P" during periods coinciding with these oceanographic surveys are also entered in the figure. Because the data obtained during the several surveys in the summer of 1956 (Pacific Oceanographic Group, 1957a) were scattered in space and time they were combined by averaging the concentrations in "Squares" of 2.5° of latitude by 5° of longitude. However, because of the timing of the surveys and the distribution of stations this plot may include seasonal effects in spite of the averaging. The 1957 data (Pacific Oceanographic Group, 1957b, c) were obtained during two surveys of about 6 weeks' duration each, sufficient time for seasonal trends to occur (see Fig. 8). Short-term (Fig. 8) and diurnal (see below) variations complicate the distributions and the data are unevenly distributed around station "P". Thus, the contours entered on Fig. 14 are, at best, rough approximations.

However, it is tentatively concluded that concentrations of zooplankton at or near station "P" fall within the range of concentrations observed in that part of the Gulf of Alaska roughly coinciding with the diffuse boundary between "midgulf" and "offshore" water (Fig. 3, 5).

2. VERTICAL DISTRIBUTION

Vertical distributions of zooplankton at station "P" were calculated from the differences in catches of overlapping vertical hauls from successive depths to the surface. The results are summarized in Fig. 15 and 16.

The vertical distribution was usually characterized by two layers of maximum abundance separated by a layer of low abundance. The upper maximum occurred within the upper 150 m and was most often found within the upper 100 m, while the deeper maximum was on the average a broad one extending
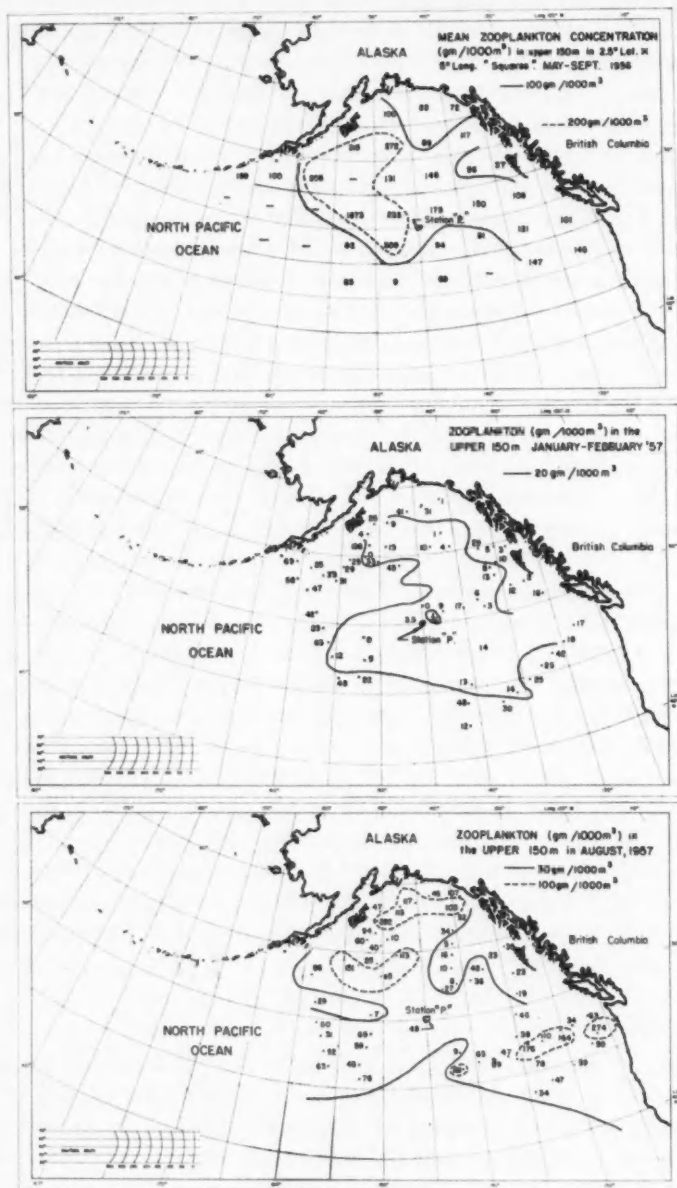
FIG. 14.   Some distributions of zooplankton in the Northeast Pacific.
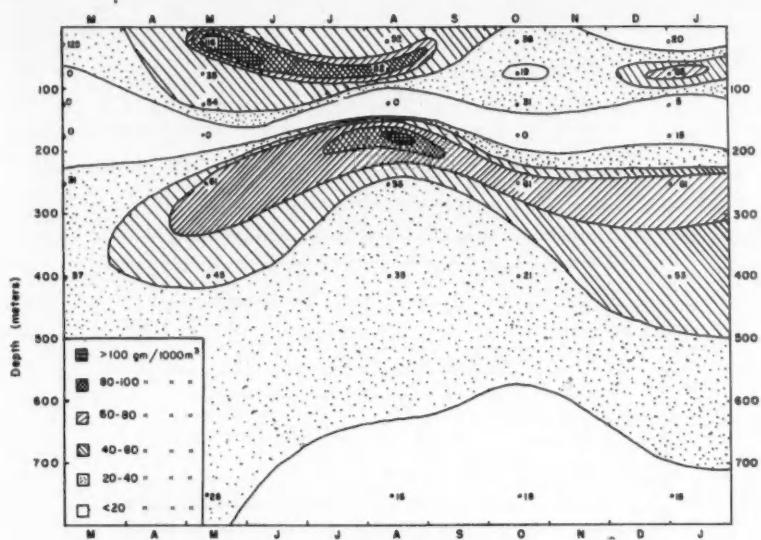
FIG. 15.   The vertical distribution of zooplankton at station "P".

between depths of 200 and 500 m.   The minimum layer between the two maxima occurred between depths of 50 and 300 m but was most often found between 100 and 200 m, tending to coincide with the depth of the permanent halocline.

In a similar vertical distribution observed in the Northwest Pacific by Brodsky (1955) the layer between the two maxima coincided with an intermediate core of cold water.

The deeper layer of zooplankton exists in a stratum too dark for phytoplankton production.   In addition, the density gradient in the halocline might, to a large extent, prevent dead organisms and detritus from reaching the lower layer of zooplankton.   Thus, in order to obtain sufficient food the herbivorous zooplankton in the lower layer may have to migrate upwards periodically in order to graze in the productive upper layers.   The carnivorous zooplankton could, of course, remain in the lower layer and prey on the migrating herbivores.

The coincidence of the layer of minimum concentration with the halocline suggests that the salinity change (1‰) in the halocline forms a barrier to the organisms.   Yet, as pointed out above, some of the deeper organisms must move up through the halocline to feed.   Taxonomic work and further sampling are necessary to determine the degree of exchange between the shallow zooplankton and the large population below the halocline.

The shallow and deep layers of maximum concentration persisted through night and day in all seasons, suggesting that they are permanent features of the vertical distribution of zooplankton in the Northeast Pacific.
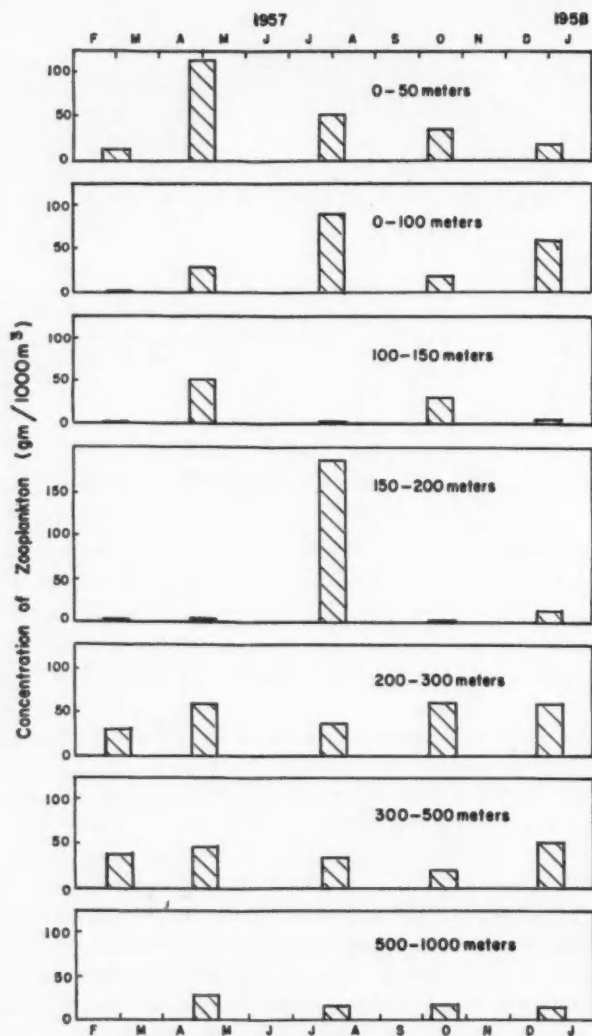
FIG. 16.   The variation of zooplankton in several depth intervals
at station "P".

3. SEASONAL VARIATION

As shown in Fig. 17, a winter minimum, a summer maximum and a secondary autumn maximum marked the seasonal cycle of concentration in the surface zooplankton at station "P". Mean 24-hour surface concentration increased from about 20 g/1000 m³ during winter (December 1956 and January 1957) to a maximum of about 150 in the following summer, then fell to about 10 in early October 1957, before rising to about 30 g/1000 m³ to form the autumn maximum. Concentrations in December 1957 and January 1958 were slightly higher than in the previous year.
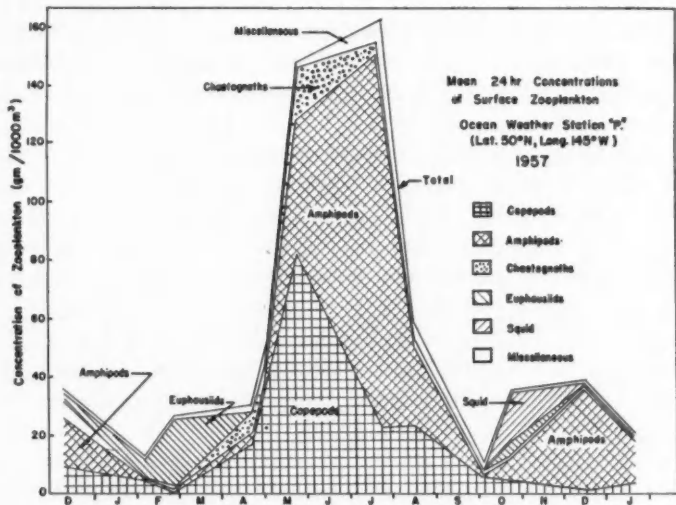
FIG. 17.   Concentration and composition of surface zooplankton
at station "P".

The concentration of zooplankton in the upper 150 m (Fig. 8) exhibited a seasonal cycle similar to the one at the surface. Concentrations averaged about 3.5 g/1000 m³ (range 0.3 to 5.0) during the winter of 1956–57 but were much higher, about 25 g/1000 m³ in the following early winter. The maximum concentrations were recorded in May and averaged about 80 g/1000 m³ (range 27 to 200). Although the highest concentrations were observed in May the trends (Fig. 8) suggest that the maximum was reached during June in an interval between two periods of observations. A small autumn maximum occurred in late October.

Vertical hauls from successive depths obtained between March 1957 and January 1958 are shown in Fig. 16. These data suggest that the seasonal cycle of abundance becomes much less marked below a depth of 200 m. The mean

concentrations for alternate 6-week periods within these dates exhibited a 10-fold variation in the upper 50 m, only 1- to 3-fold between depths of 200 and 500 m, and even less between 500 and 1000 m. Wiborg (1955) noted a similar phenomenon in the Norwegian Sea.

Ostvedt (1955) showed that the larger copepods at ocean weather station "M" in the Norwegian Sea descend from the upper layers in July and August to depths as great as 1000 to 2000 m and remain there until the onset of the next spring reproductive period in March and April when they again rise to the upper layers. Brodsky (1955) made similar observations in the Northwest Pacific Ocean.

While the data from station "P" are not sufficient to demonstrate this large-scale seasonal migration of copepods, they are consistent with Ostvedt's description. The larger species of copepods at station "P" were abundant in shallow hauls only during April and May, after which they occurred mainly in the deep hauls (300, 500 and 1000 m). Thus, it appears that in addition to growth, reproduction and mortality, vertical migration may be important in the seasonal variation of the abundance of copepods in the upper layers of the ocean.

Vertical and horizontal hauls gave contrasting pictures of the seasonal variation in gross taxonomic composition of the zooplankton. Typical vertical hauls at all times of year were composed of about 75% copepods, 15% chaetognaths and 10% miscellaneous groups. The contrasting seasonal variation of the taxonomic groups in the surface samples is shown in Fig. 17 (Table III). Amphipods were dominant in early winter in 1956, euphausids in late winter, copepods in April and May, amphipods in mid-summer, squid and copepods in the fall, and amphipods again in the following winter.

TABLE III. Percentage composition of 24-hour mean catch of surface zooplankton at ocean weather station "P".

Date	Copepoda	Chaetognatha	Amphipoda	Euphausiacea	Squid	Others
	%	%	%	%	%	%
10-XII-56	27	15	49	9	. . .	. . .
7-II-57	34	3	1	62	. . .	. . .
27-II-57	1	tr.	5	92	. . .	2
25-IV-57	57	25	14	1	. . .	3
3-V-57	72	11	5	12	. . .	. . .
23-V-57	55	13	31	tr.	. . .	1
16-VII-57	14	3	80	. . .	. . .	3
13-VIII-57	4	1	87	tr.	5	3
4-X-57	54	6	3	3	26	8
18-X-57	13	2	21	13	51	. . .
20-XII-57	4	tr.	91	5	. . .	. . .
22-I-58	18	1	68	13	. . .	. . .
Mean	29.6	6.7	37.8	17.5	6.8	1.6

4. DIURNAL VARIATION

(a) SURFACE TOWS

A pronounced diurnal variation in the concentration of surface plankton was observed during each of the 24-hour series of bi-hourly surface tows taken at station "P" (Fig. 10, 11, 12, 13). The average of the ratios of mean night to mean day concentrations observed during 24-hour series of surface plankton hauls is about 8, with a range of 0.2 to 37.

Cushing (1951) in his excellent review of the diurnal vertical migrations of zooplankton, states that organisms undertaking a typical migration rise towards the surface during the evening, sink during the darkness near midnight, rise again before dawn and migrate actively downwards near sunrise. Thus, in the surface layer one would expect to find two nocturnal maxima of concentration separated by a minimum near midnight and low concentrations during the day.

Only 2 of the 12 surface series taken at station "P" conform exactly to Cushing's concept of a typical diurnal migration. Seven other series do exhibit two nocturnal maxima of concentration but also display one or more peaks of concentration during the daylight hours. Of the remaining 3 series, 1 reveals a daylight and a single nocturnal maximum, and two have a single maximum occurring at night (Fig. 10).

It is evident that the diurnal cycle of surface concentration was a variable one. However, the main features of the typical diurnal migration described by Cushing (1951) occurred in 9 of the 12 series, and mean night concentrations exceeded mean daylight concentrations in 10 series. The two instances in which day concentrations exceeded those observed at night occurred in the winter of 1957–58 and were associated with high daylight concentrations of amphipods (Fig. 13). Similar daylight maxima of amphipods were observed in December 1956. However, in the latter case a nocturnal increase in the concentration of copepods occurred and the mean night concentration exceeded the daylight average.

(b) VERTICAL HAULS

On six occasions vertical hauls from successive depths to the surface were made in the morning and after dark of the same day. The mean ratios of night/day concentrations for these hauls are presented in Table IV, and are greater than 1 in each case.

Wiborg (1955) compared night and day catches of zooplankton from surface tows and 25 and 100 m vertical hauls made at ocean weather station "M" in the Norwegian Sea. These ratios are also greater than 1 (Table IV).

The higher catches of zooplankton at night could result from diurnal vertical migration, or the ability of organisms to dodge nets in daylight.

TABLE IV. Mean ratios of night concentration to day concentration of zooplankton.

Depth of haul	Station "P"	Wiborg (1955) station "M"	King and Hida (1957) Central Equatorial Pacific
m			
Surface	8.1	14.5	. . .
0 to 25	. . .	1.7	. . .
0 to 50	17.5(3.0)ᵃ	. . .	. . .
0 to 100	2.1	1.4	. . .
0 to 150	2.8	. . .	. . .
0 to 200	1.8	. . .	1.5
0 to 300	1.6	. . .	. . .
0 to 500	1.2	. . .	. . .

ᵃThe mean ratio for 0 to 50 m is lowered to 3.0 if one extremely high value is excluded.

On the average, the nocturnal increases in the percentage of the total zooplankton (0 to 500 m) to be found in some of the shallower depth intervals were accompanied by a decrease in the percentage present in the depth range from 300 to 500 m (Table V).

TABLE V. Diurnal variation of the proportion of the total zooplankton in the water column (0 to 500 m) present in various depth intervals at station "P". Figures shown are percentages of the total zooplankton taken in each day or night series.

Date	0–50 m Day	0–50 m Night	50–100 m Day	50–100 m Night	100–150 m Day	100–150 m Night	150–200 m Day	150–200 m Night	200–300 m Day	200–300 m Night	300–500 m Day	300–500 m Night
31-VII-57	76.1	24.2	0.3	5.3	0.3	2.1	23.0	34.2	0.3	33.8	. . .	. . .
15-VIII-57	4.7	13.2	6.5	0.0	19.6	2.6	0.0	4.4	0.0	18.9	69.0	61.0
8-X-57	13.6	30.8	0.0	0.0	23.2	6.2	1.1	53.7	6.5	9.3	55.5	0.0
28-X-57	1.3	14.6	8.6	0.0	11.8	0.0	0.0	1.0	23.8	56.3	54.4	28.1
23-XII-57	1.1	7.3	12.7	18.9	0.0	2.5	7.0	2.5	47.8	31.0	31.4	37.7
16-I-58	2.7	7.1	6.0	12.5	0.0	5.1	6.9	0.0	32.6	28.4	52.1	47.0
Meanᵃ	4.7	14.5	6.8	6.3	10.9	3.3	3.0	12.3	22.1	28.6	52.5	35.0

Frequency with which Night percentage exceeded Day percentage
  5/6   3/6   3/6   4/6   4/6   1/5

ᵃPercentages from 31-VII-57 excluded.

It would be attractive to assume that the nocturnal redistribution of zooplankton resulted from vertical migration. However, diurnal differences in the catches of zooplankton due to the ability of organisms to dodge nets in daylight must be greater in the shallow lighted layers than in the darker deep layers, since the diurnal range of light intensity decreases rapidly with depth (e.g., 0.5 to 0 langleys/min at the surface, 10^{-8} to 0 at about 300 m). The increased catches of zooplankton at night in the shallower layers would lead to an apparent decrease in the proportion of the total zooplankton to be found in the deeper layers.

The mean ratio of the *amount* of zooplankton present in the 300–500-meter layer at night to that in the daytime is only 1.1, while the average of the ratios in 5 depth intervals above 300 m is over 5 (see Fig. 18). The small nocturnal change below 300 m could be interpreted to support the theory that the apparent diurnal change in vertical distribution of the total zooplankton is due to a diurnal change in the vertical gradient of catchability. However, the low ratio of night/day amounts of plankton in the 300–500-meter layer could also result if the zooplankton migrating out of this layer at night was replaced by organisms moving up from even greater depths.

Wiborg commented on the difficulty of distinguishing between diurnal cycles of concentration, and diurnal variations in catchability, but nevertheless concluded from the decrease of the night/day ratio with depth that most diurnal vertical migration in the Norwegian Sea occurs within the upper 200 m of water.
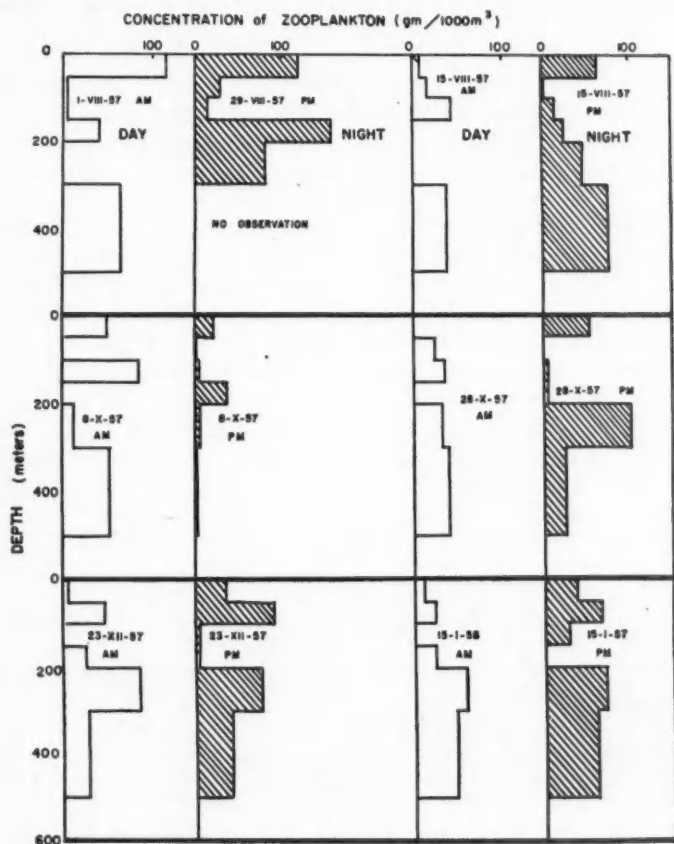
FIG. 18. Diurnal variation of zooplankton with depth at station "P".

King and Hida (1957) found that night catches were about $1\frac{1}{2}$ times the day catches from 200-meter oblique hauls in the central Equatorial Pacific (Table IV) and, like Wiborg, mentioned the difficulty of distinguishing between diurnal variation of concentration and variations in catchability. It will be seen that the night/day ratios found by Wiborg (1955) and King and Hida (1957) are within an order of magnitude of those observed at station "P". In view of their separation in distance, time, and technique, better agreement cannot be anticipated.

Although diurnal migration cannot be directly demonstrated from the present data it is certain that it occurs at least to some extent at station "P". Investigations by many authors (see Cushing, 1951) suggest its widespread occurrence and most of the 24-hour series of surface observations showed some of the major features of the typical migration described by Cushing.

5. Speculation on the Availability of Zooplankton at Station "P"

For the purposes of this discussion availability may be regarded as the fraction of the total zooplankton in a water column which a given fish could consume under the prevailing environmental conditions. The *amount* of zooplankton available would then be the product of the total zooplankton and the availability.

(a) Availability and depth

The amount of zooplankton available to sight-feeding fish must partly depend on light as well as the concentration of zooplankton and other factors. The effect of the variation of light with depth on the availability will in turn depend on the vision of the fish in question.

Brett (1957) reports that juvenile coho salmon (*Oncorhynchus kisutch*) fed normally at light intensities between about 10^{-8} langleys per minute (ly/min) and 0.2 ly/min, the highest light intensity used. Below 10^{-8} ly/min the rate of feeding decreased and at 10^{-9} ly/min it was only 3% of normal. Thus, reducing the light by a factor of 10 reduced the availability of food by a factor of about 30. In total darkness no feeding occurred. A light intensity of 10^{-8} ly/min may be regarded as the lower threshold illumination for normal feeding.
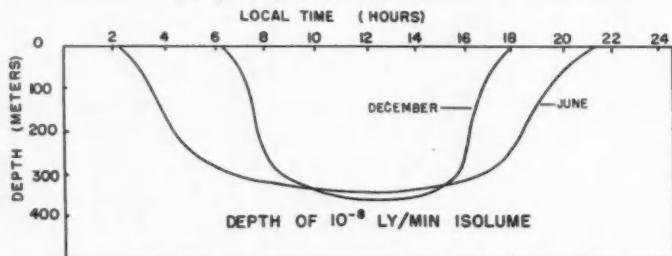
Fig. 19.   Depths of the 10^{-8} langley/minute isolume at station "P".

The approximate depths of the 10^{-8} ly/min isolume at station "P" during a day in June and a day in December are presented in Fig. 19. It is evident that fish with vision similar to that of juvenile coho should be able to feed without light restriction down to maximum depths of 300–350 m. Thus, the layer of relatively rich zooplankton between 200 and 300 m would be readily available to such fish. However, factors such as salinity, temperature or pressure may prevent the fish from attaining this depth range. Also, if gradients in the zooplankton concentration affect the movements of feeding fish, the layer of minimum concentration between 100 and 200 m might deter them from moving down into the richer layer.

It is not known how representative the data on juvenile coho may be of the vision of other fish. Calculations from data on herring (Battle *et al.*, 1936; Marshall and Orr, 1955) suggest that the lower threshold illumination for normal feeding by these fish is somewhat greater than 10^{-7} ly/min. Grundfast (1932) reports that the lower limit of vision in *Lepomis* occurs at a light intensity equivalent to 10^{-11} ly/min. It has been pointed out (Strickland, 1958) that optimum feeding probably occurs at a higher light intensity.

Figure 19 suggests that the depth range through which fish may feed without light restriction is relatively constant through the daylight hours but becomes sharply reduced at night. Near sunset and sunrise unrestricted feeding may be limited to the top few meters. However, the results of surface sampling indicate that there is often a rich supply of food near the surface at these times.

(b) SEASONAL VARIATION

The seasonal cycle of zooplankton observed at station "P" doubtless reflects variations in the amount and kind of food available to sight feeding fish.

Seasonal variation in day length (e.g. Fig. 19) may tend to enhance the effect of the cycle of abundance on the zooplankton available to a given fish. During the summer zooplankton maximum the long days permit protracted feeding. In winter the coincidence of short days with generally sparse zooplankton suggests that the amounts available may be even less than are indicated by concentrations alone. It seems not impossible that winters with very sparse zooplankton, heavy cloud cover and unusual turbidity could be critical periods for the survival of young fish.

Seasonal variations in the response of zooplankton to light could also affect their availability. The tendency for amphipods at station "P" to occur at the surface usually near darkness in spring and mostly during broad daylight in early winter is a possible example.

(c) DIURNAL VARIATION

Diurnal ranges of composition and abundance in the surface zooplankton at station "P" may approach seasonal ranges but may or may not reflect diurnal cycles of availability.

If the diurnal variations result from vertical migration, the same organisms available to fish at the surface near dusk and dawn will occur at greater depths

during the daytime.   If the diurnally migrating zooplankton maintain position within particular light intensities, as suggested by some workers (e.g. Kampa and Boden, 1954), their availability to fish may remain constant unless vertical variation of salinity, temperature and pressure restrict movement of the fish.

On the other hand, other workers (e.g. Clarke and Backus, 1956) suggest that on being stimulated to swim upward by a decrease in illumination, some organisms may rise into water having light intensities much higher than those originally inhabited.   Presumably, the reverse would occur with decrease of light. In such cases, diurnal variations in availability are possible.

Marshall and Orr (1955) quote authors and mention evidence suggesting that young herring feed most actively from 5 to 9 p.m. and during a period near dawn, times when vertically migrating zooplankton should be near the surface (Cushing, 1951).   Nemoto (1957) indicates that baleen whales tend to feed largely in the early morning and evening and suggests that this may be partly a response to the diurnal migrations of food organisms.   Thus, it seems possible that plankton feeders as diverse as herring and whales may respond to diurnal cycles in the availability of food.

(d) General

Food supply must be one of the major factors affecting the occurrence, growth, movements and even survival of fish.   General abundance of zooplankton has often been used as an index of feeding conditions and of the occurrence of fish. However, some studies suggest that general abundance alone is an incomplete criterion.

Thus, although Laevastu (1957) implies that catches of Pacific salmon (*Oncorhynchus* spp.) are greatest in regions of generally abundant zooplankton, Allen (1956a, b, c) noted discrepancies between the catches of vertical hauls and stomach contents of salmon.   Vertical hauls caught mainly copepods while stomachs contained amphipods, squid and euphausiids, sometimes in pure culture and frequently as major fractions.   Allen (1956c) suggests that surface samples would give a better indication of the occurrence of organisms known to be eaten by salmon than vertical hauls.   The preliminary results from station "P" support Allen's suggestion.

Battle *et al.* (1936) found no relation between distributions of fatness of young Passamaquoddy herring and total zooplankton.   Instead, fatness was found to be related to the distribution of surface zooplankton.   This correlation must have resulted from the interaction of the vertical distribution of zooplankton and the feeding behaviour of the fish.

In addition to positive correlations between the occurrences of zooplankton and herring in the Barents Sea, Manteufel (1941) also found negative correlations, and at times none.   As a result of detailed study, Manteufel was able to explain the varying relationship in terms of the life cycles and behaviour of both fish and zooplankton.

If knowledge of the effects of zooplankton on survival, growth, movements

and occurrence of fish is to pass the stage of crude qualitative correlation, many factors in addition to general abundance will require combined study. Light responses, depth ranges, behaviour, diurnal migration, diets of fish and rates of production of zooplankton are among these factors.

Separate study of many of these factors has been done, but only rarely have the results been combined in an attempt to understand food relationships. Use of a concept such as availability would be valuable in combining past results and in planning future zooplankton–fisheries work.

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Contribution to the Biology of Herring (*Clupea harengus* L.) in Newfoundland Waters[1]

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ABSTRACT

A study of the herring of the south and west coasts of Newfoundland in 1957 and 1958 revealed no great fluctuations in relative year-class strength and indicated a fairly high survival rate from the age of recruitment to the fishery.

The rate of growth was higher than that found by Tibbo (1956) in 1942–44, and no significant difference in growth rate was demonstrated between the south coast and the region of Bay of Islands and Port au Port Bay.

The study indicated an unusual spread in spawning time with probably peaks in spring, autumn and winter, while prior to about 1950 the Newfoundland herring were apparently all spring spawners. It is suggested that this has caused changes in the traditional pattern of distribution, which have been unfavourable for the herring fishery, and it may also have resulted in an actual decrease in population size.

INTRODUCTION

THE HERRING FISHERY in Newfoundland, which during and shortly after the war period was of a considerable magnitude, with a record of 164 million pounds landed in 1946, has over the last decade declined rapidly. This decline has been fairly uniform in all areas of the island, and to such an extent that only in the region of Bay of Islands and Port au Port Bay did a regular fishery of any significant proportion remain uninterrupted until last year.

Poor market conditions for herring products and other economic factors in the postwar period quite likely contributed to the decline of the herring fishery, but many people of the industry are of the opinion that the reduced landings have also been associated with a marked decrease in abundance of herring. Thus, in Fortune Bay, for instance, which previously was one of the centres of the herring fishery, no large quantities of herring have been observed for many years.

From 1942 to 1944 and again from 1946 to 1948, Tibbo (1956, 1957b) carried out herring investigations in Newfoundland waters, especially in the Fortune Bay and Bay of Islands areas. For the next 9 years some minor exploratory experiments were carried out in limited areas, but no general survey of the Newfoundland herring resources was conducted during this period.

Then, from June 1957 to September 1958 a project of herring research and exploratory fishing was undertaken by the Fisheries Research Board of Canada

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Biological Station, St. John's, Nfld., and with financial aid from the Industrial Development Service, Department of Fisheries of Canada.

The 57-foot M.V. *Matthew II*, chartered from the Newfoundland Department of Fisheries, was operated in exploratory fishing experiments with gill nets used as drift nets near the surface and as set nets at the bottom. The vessel was also used for searching with asdic/echo-sounder and for hydrographic and plankton surveys.

During summer and autumn both inshore and offshore waters on the south and west coasts were explored, but in the winter months operations were restricted to Placentia Bay and Fortune Bay on the south coast.

The results of the exploratory fishing and the echo surveys indicated that, during summer, the herring are sparsely distributed offshore in the warm surface layer of water, with possible aggregations off the west coast in areas of large horizontal temperature gradients. They may also, at this time of year, occasionally accumulate in the many bays and inlets of the island, but in the autumn, winter and spring they are found inshore more regularly and in larger concentrations.

The present paper is based on the material for biological statistics collected during the operation of the *Matthew II*, supplemented with a few samples obtained from local fishermen. Thus, it refers almost entirely to the herring on the south and west coasts of Newfoundland, as there is no material from the northeast coast, with the exception of 2 samples from White Bay and one from Trinity Bay.

MATERIAL AND METHODS

Table I gives a record of the samples, localities and methods of capture, and Fig. 1 shows the place names referred to in the table and elsewhere in this paper.

TABLE I. List of samples, localities and methods of capture.

Date	Locality	Total catch*	Scales	Sample Lengths	Sex and maturity	Method of capture	Size of nets, stretched mesh
1957		*numbers*					*inches*
June 18	St. George's Bay	(5)	100	324	100	Drift nets	2⅞
" 19	Bay of Islands	52	. . .	50	. . .	Set nets	2⅞
" 23	Bonne Bay	55	. . .	54	. . .	Set nets	2⅞
" 26	Hermitage Bay	. . .	86	86	86	Drift nets	unknown
" 27	Hermitage Bay	(2½)	160	391	211	Drift nets	2⅝
July 16	Hermitage Bay	18	. . .	18	18	Set nets	2⅝
" 17	Hermitage Bay	188	186	186	186	Drift nets	2⅞
" 18	Hermitage Bay	24	. . .	24	24	Set nets	2⅞
" 19	Connaigre Bay	32	. . .	29	32	Drift nets	2⅞
" 31	Off Bonne Bay	(11)	100	265	265	Drift nets	2⅞

*Numbers in brackets give quantity in barrels.

TABLE I—*Continued*

Aug.	1	Off Cow Head	58	...	58	58	Drift nets	$2\frac{7}{8}$
"	8	Off Point Riche	37	...	37	37	Drift nets	$2\frac{7}{8}$
"	9	Strait of Belle Isle	$(1\frac{1}{2})$	100	300	300	Drift nets	$2\frac{7}{8}$
"	9	Old Perlican, T.B.	...	65	65	65	Cod trap	unknown
"	17	Conche, White Bay	...	180	180	180	Set nets	unknown
"	28	Port aux Basques	45	...	44	44	Set nets	$2\frac{7}{8}$
"	29	Harbour Le Cou	...	100	162	162	Set nets	unknown
Sept.	23	Fortune Bay	60	54	54	54	Set nets	$2\frac{7}{8}$
"	25	Fortune Bay	30	...	18	17	Set nets	$2\frac{7}{8}$
"	26	Fortune Bay	20	19	19	19	Drift nets	$2\frac{7}{8}$
"	26	Fortune Bay	30	25	27	27	Set nets	$2\frac{7}{8}$
Oct.	16	Bay of Islands	1,185	237	957	957	Drift nets	$2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}$
"	17	Off Port au Port Bay	94	92	92	92	Drift nets	$2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}$
"	18	Off Port au Port Bay	646	130	644	514	Drift nets	$2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}$
"	19	Port au Port Bay	42	...	42	42	Set nets	$2\frac{1}{4}, 2\frac{1}{2}$
"	19	Port au Port Bay	560	...	435	435	Set nets	$2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}$
"	24	Bay of Islands	866	...	866	...	Drift nets	$2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}$
"	25	Bay of Islands	65	...	65	...	Set nets	$2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}$
Nov.	8	Port au Port Bay	...	100	224	224	Purse seine	...
"	8	Port au Port Bay	...	...	165	...	Purse seine	...
"	19	Fortune Bay	51	...	51	51	Set nets	$2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}$
1958								
Jan.	4	Fortune Bay	...	105	105	105	Set nets	unknown
"	21	Placentia Bay	$(1\frac{1}{2})$	116	416	116	Set nets	$2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}$
"	24	Placentia Bay	47	47	47	47	Set nets	$2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}$
"	29	Placentia Bay	79	...	79	79	Set nets	$2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}$
"	29	Placentia Bay	320	100	320	100	Set nets	$2\frac{3}{4}$
"	29	Placentia Bay	316	...	316	...	Set nets	$2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}$
Feb.	5	Fortune Bay	31	27	31	31	Set nets	$2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}$
"	10	Fortune Bay	33	...	33	33	Set nets	$2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}$
Mar.	14	Placentia Bay	355	100	337	100	Set nets	$2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}$
April	1	Fortune Bay	15	...	12	12	Drift nets	$2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}$
May	4	Fortune Bay	...	...	45	45	Beach seine	unknown
"	5	Fortune Bay	...	...	612	162	Beach seine	unknown
June	3	Hermitage Bay	707	...	707	277	Drift nets	$2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}, 2\frac{7}{8}$
"	8	St. George's Bay	159	...	159	159	Drift nets	$2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}, 2\frac{7}{8}$
"	12	St. George's Bay	50	...	50	50	Drift nets	$2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}, 2\frac{7}{8}$
"	14	Hermitage Bay	225	...	223	223	Drift nets	$2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}, 2\frac{7}{8}$
"	18	St. Mary's Bay	388	...	388	388	Set nets	$2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}$
July	9	Off Portland Hill	20	...	20	20	Drift nets	$2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}, 2\frac{7}{8}$
"	16	Bay of Islands	24	...	24	...	Set nets	$2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}$
"	16	Bay of Islands	...	...	31	...	Set nets	unknown
"	17	Off Point Riche	67	...	67	67	Drift nets	$2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}, 2\frac{7}{8}$
"	21	Conche, White Bay	...	...	128	128	Set nets	unknown
"	26	Bonne Bay	41	...	41	41	Set nets	$2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}$
"	31	Current Island	213	...	213	213	Set nets	$2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}$
Aug.	27	Bay of Islands	39	...	39	...	Drift nets	$2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}, 2\frac{7}{8}$

FIG. 1.   Location of place names referred to in the text.

Catches of less than approximately ½ barrel were usually sampled in total. Most catches were very small and, in some cases, samples of several catches from the same area and caught during a short period of time have been combined.

The greatest total length was measured to the nearest ½ centimetre (i.e. the distance from the tip of the lower jaw, with the mouth closed, to the end of the longest lobe of the caudal fin extended straight back in line with the body).

The gill nets are selective in their mode of fishing, and the length-frequency distributions were therefore adjusted for the effect of mesh selection by means of Holt's (1957) method, using the selection curves and the procedure described by the author in a previous paper (Olsen, 1959).

From the adjusted length-frequency distributions the age distributions were calculated by means of the age-length-key method.

The age determinations were made by means of the scales. It was observed that the first growth zone varied much in size and this is probably caused by the great spread in spawning time. However, the variation in size of the first growth zone appeared to be continuous, with no particular peaks. Therefore, no success was achieved in distinguishing between, for example, spring-spawned and autumn-spawned herring. The age was therefore determined as the number of completed growth zones and the first of January was arbitrarily chosen as the "birth date".

This procedure would lead to an underestimation of the age of fish spawned so late in the year that the first winter zone is not laid down in the scale (Jean, 1956) and the effect on the estimated age distribution would be to reduce the mean age and to dampen fluctuations in relative year-class strength, as discussed by Gulland (1955).

Condition of maturity was determined in 8 stages using the descriptions given by Aasen (1952). There was probably not complete consistency between the different field observers in determining the various degrees of ripening (stages III, IV, V and VIII), but they would have no difficulty in identifying a herring with running milt or roe, or a recently spent fish.

AGE AND GROWTH

Age and Length Distribution

In Fig. 2 and 3 are shown the age and length distributions adjusted for the effect of mesh selection for samples from various localities on the south and west coasts of Newfoundland.

In the summer samples from the west coast the length distributions do not differ very much; fairly large numbers of age-groups are represented in all samples and no particular year-class stands out as being exceptionally strong or weak.

The samples from the region of Bay of Islands and Port au Port Bay, taken in the autumn, differ considerably in age and length composition among themselves and on the whole they show some differences from the other west coast samples. The length curves are to some extent bimodal, the length range is usually greater
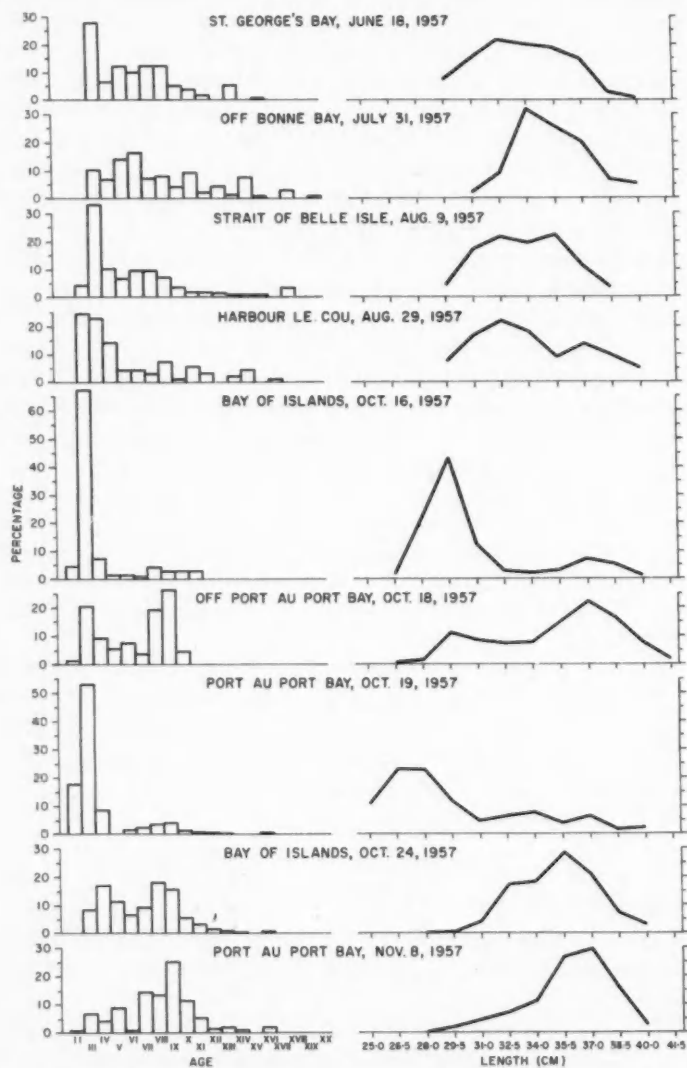
FIG. 2.   Age and length distribution of herring samples in various localities
from Harbour Le Cou to the Strait of Belle Isle.
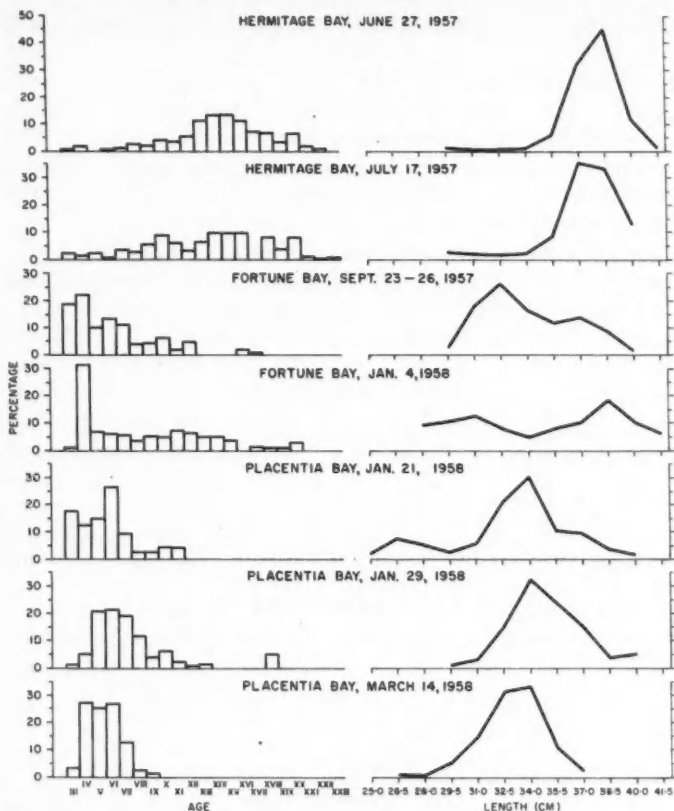
FIG. 3.   Age and length distribution of herring samples from the south coast of Newfoundland.

and the age distributions are more irregular than those of the summer samples, and indicate fluctuations in year-class strength.

Thus, the VIII- and IX-groups were well represented in nearly all samples, and the VI-group was persistently weak.   The greatest variation was found in the number of young fish below this age.   Therefore, it would seem that in the same general area the catches were made up of herring 6 years or older mixed with varying amounts of younger fish.   In some cases the young fish dominated, in others there were about equal amounts of both groups and in some catches the old fish were dominant.

On the south coast the herring in Hermitage Bay were very large and old, ranging from 3 to 23 years in age, with the peak at about age 14–15.   The Fortune Bay herring were on an average smaller, but also in this bay a large number of age-groups were present, though with the younger fish in greatest abundance.

The smallest herring were found in Placentia Bay, which practically lacked fish over 12 years of age.

The herring fishery on the south coast has in the past decade been at a very low level, and unless the population size was extremely small, it is rather unlikely that the age composition has been much affected by the fishery.

Thus a trend of geographical segregation with age is indicated on the south coast, with a westward distribution of the large and old fish, and a concentration of the younger age-groups in the east, in Placentia Bay.

The data present no evidence of violent fluctuations in relative year-class strength, and in general the age distribution of the samples, particularly those from Hermitage Bay, would indicate a high survival rate after the age of recruitment to the fishery.

RATE OF GROWTH

In Fig. 4 the mean lengths are plotted against age at capture in 4 different areas, viz. Strait of Belle Isle, Bay of Islands and Port au Port Bay, Hermitage Bay, and Placentia Bay.

With the exception of the right-hand part of the Strait of Belle Isle curve, the mean length curves indicate a fairly uniform growth rate in all localities. The growth is rapid and quite appreciable right up to the high age of 20 years.

These observations differ from those of Tibbo (1956) in two ways. Firstly, the growth rate revealed by the present data is considerably higher than found by Tibbo in 1942–44 in any one area. The difference in mean lengths from
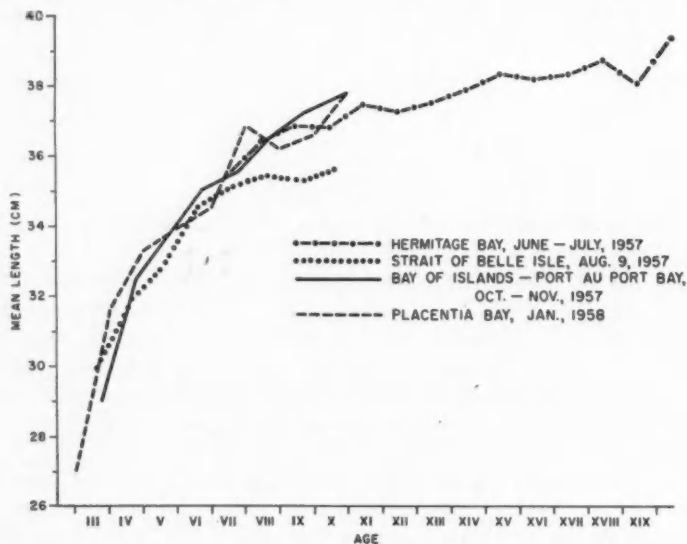
FIG. 4.   Mean lengths plotted against age at capture in four different areas.

ages 5 to 10, for instance, between these and Tibbo's data from Fortune Bay increases with age from about 1 cm to over 2 cm.

Secondly, Tibbo demonstrated significant differences in growth rate between different areas, of which there is little evidence in the present data.   In particular, the growth rate on the south coast seems to be very similar to that in the area of Bay of Islands to Port au Port Bay.

As pointed out by Tibbo, his growth curves are certain to be affected by gear selectivity, as no attempt was made to adjust for this effect.   The effect would tend to reduce the calculated growth rate, as discussed by Ricker (1958, p. 187), and for comparison we should consider the magnitude of this reduction.

In Fig. 5, two mean length curves are shown for data from Bay of Islands and Port au Port Bay; one is adjusted for the effect of mesh selection, the other is unadjusted.   Apparently the maximum difference in mean lengths, that at age 10+, is only of about 0.6 cm, and it is practically nil at the lower ages.   Thus, it seems very unlikely that the effect of gear selection in Tibbo's estimates can account for anything but a small part of the difference in mean lengths between the present data and those of Tibbo.

The difficulties encountered in the interpretation of the first year's annulus in the scales, which have been mentioned before, might bias the age readings of the present material, but would not contribute to a larger error than one year
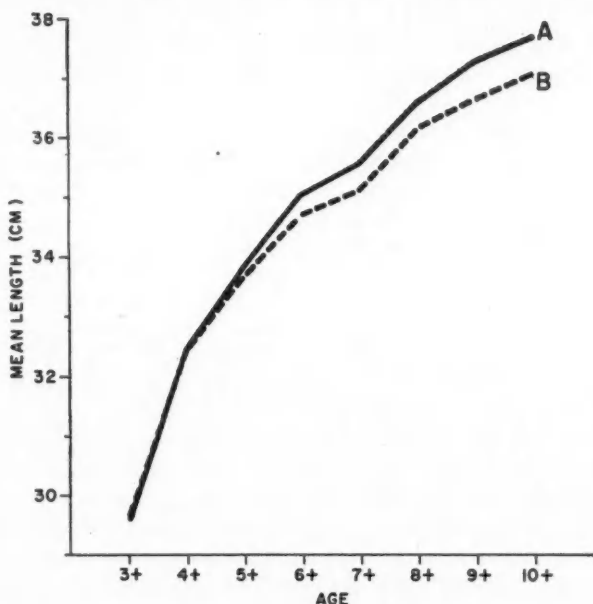
FIG. 5.   Mean length curves for combined samples Bay of Islands–
Port au Port Bay area.   A—adjusted for effect of mesh selection.
B—unadjusted.

in the individual fish, and on an average less. Even if we assume a consistent underreading of one full year, the mean lengths of the present data and those of Tibbo are considerably different. Consequently, unless there is something basically wrong in our age readings, the difference in growth rate is real.

In Tibbo's 1942–44 samples (Tibbo, 1956) from the south and west coasts of Newfoundland only a few herring of 37 cm or larger were present, and in his 1946–48 samples (Tibbo, 1957b) from the same areas few herring of 38 cm or larger were found.

This study indicates that herring of 37–39 cm are quite common in most localities, even excluding the very large fish in Hermitage Bay. This, of course, could be due to a greater survival in recent years, but would also be a result of a general increase in growth rate.

Thus, this investigation indicates that *the rate of growth of Newfoundland herring is at present considerably higher than in the years of the good fishery during the war and shortly afterwards.* Also, this study has revealed no significant difference in growth rates between the south coast and the area of Bay of Islands and Port au Port Bay.

REPRODUCTION

LENGTH AND AGE AT MATURITY

Most herring caught in Newfoundland are large, sexually mature fish, and the habitat of the immature (juvenile) part of the population is practically unknown.

During the present surveys only on a few occasions did the catches include appreciable amounts of immature herring, and from these it appeared that 50% of the herring of 27–28 cm had reached sexual maturity. The smallest mature fish was 24 cm and the largest immature one was 33.5 cm. This would indicate that the Newfoundland herring mature during the third to sixth year of life.

SPAWNING TIME

Table II records the percentages of herring in the various maturity stages from III to VIII in different localities and at different times; and Fig. 6 shows the percentage distribution by month for the entire material.

It appears that the numbers of herring in the spawning stage (VI), and, to some extent also the numbers of fish recently spent, are small, although samples were secured from all months of the year with the exception of April and December. Evidently this is partly a result of the nearly constant change in locality or area of fishing, but it is probably caused by the methods of fishing also. Whenever possible the method used was drift-netting near the surface and, consequently, no amount of spawning herring could be expected to be caught during these operations. Thus, the largest numbers of spawning herring were taken during the winter months when the nets were usually set at the bottom.

TABLE II. Percentage distribution of maturity stages.   (Immature fish excluded.)

Date	Locality	Maturity stages in %						N
		III	IV	V	VI	VII	VIII	
1957								
June 18	St. George's Bay	...	3.0	1.0	...	96.0	...	100
June 26, 27	Hermitage Bay	8.1	41.0	28.1	...	20.0	2.7	295
July 16, 19	Hermitage Bay and Connaigre Bay	60.5	14.5	13.7	...	5.1	6.3	256
July 31, Aug. 1	Off Bonne Bay and Cow Head	38.0	45.6	6.4	...	2.1	7.9	329
Aug. 8, 9	Strait of Belle Isle and off Pt. Riche	45.1	36.2	12.5	....	...	4.2	335
Aug. 8, 9	Old Perlican, T.B.	18.8	56.3	21.9	...	...	3.1	64
Aug. 17	Conche	8.9	73.8	16.2	...	...	1.1	179
Aug. 28, 29	Port aux Basques and Hbr. Le Cou	15.6	64.8	18.1	...	...	1.5	199
Sept. 23–26	Fortune Bay	27.0	17.4	50.4	5.2	...	...	115
Oct. 16	Bay of Islands	85.1	12.3	1.7	0.4	...	0.6	701
Oct. 17, 18	Off Port au Port Bay	81.8	15.1	3.1	...	...	...	192
Oct. 19	Port au Port Bay	93.4	5.7	1.0	...	...	...	317
Nov. 8	Port au Port Bay	60.9	26.4	12.3	0.5	...	...	220
Nov. 19	Fortune Bay	94.5	2.8	...	...	...	2.8	36
1958								
Jan. 4	Fortune Bay	42.9	25.7	4.8	1.0	21.0	4.8	105
Jan. 21, 24	Placentia Bay	46.0	25.2	11.7	2.5	2.5	12.3	163
Jan. 29	Placentia Bay	13.4	6.1	11.2	12.3	19.6	36.9	179
Feb. 5–10	Fortune Bay	71.2	18.6	3.4	...	3.4	3.4	59
Mar. 14	Placentia Bay	28.0	25.0	14.0	2.0	...	31.0	100
May 4, 5	Fortune Bay	74.1	11.7	11.1	...	1.9	1.2	162
June 3	Hermitage Bay	64.4	6.8	0.5	...	3.2	25.2	222
June 18	St. Mary's Bay	47.8	17.1	1.6	1.0	...	32.6	387
July 9, 17	Off Portland Hill and Pt. Riche	64.4	27.6	4.6	...	1.2	2.3	87
July 21	Conche	62.7	13.5	1.6	...	...	22.2	126
July 26	Bonne Bay	79.0	...	...	10.5	10.5	...	19
July 31	Current Island	58.5	27.8	8.0	1.4	0.5	3.8	212

However, in spite of the lack of representative samples of herring in the actual spawning stage, some conclusions regarding the spawning time can be made from circumstantial evidence, such as the time distribution of nearly ripe (stage V) and recently spent (stage VII) fish.

The development of the gonads may be retarded for long periods when the herring inhabit cold waters, as mentioned by Tibbo (1956) and by Devold (1959). Consequently, the presence of nearly ripe fish does not necessarily infer that they are about to spawn shortly afterwards. On the other hand the recently spent herring recover rapidly, as stated by Tibbo (1957a) and by Aasen (1952).

Re-examining Table II we notice that the samples from the summer of 1957 included 2 groups which were distinctly out of phase as regards development of the gonads.   In one group the gonads in the latter part of June showed evidence of a recent spawning, after which they recovered fairly quickly; and by the end of July to the beginning of August they had mostly reached maturity stage III. In June the other group already had fairly well developed gonads in stages IV and V.   The ratio between the numbers in stages IV and V remained fairly steady
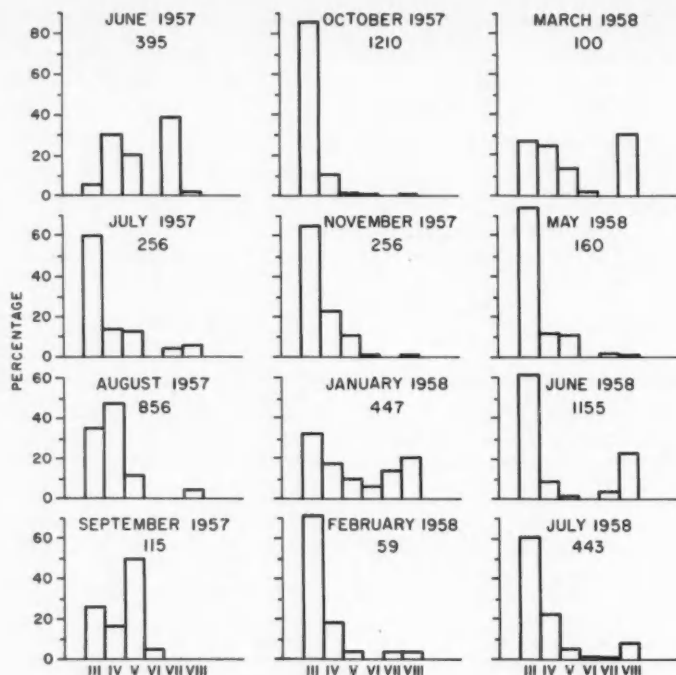
FIG. 6.   Monthly percentage distribution of maturity stages III to VIII.
All data combined.

during July and August, possibly because the herring become less vulnerable to drift-net fishing when they approach the spawning stage.

However, if we assume that these fish did not seek the very cold intermediate layer of water, and it is very unlikely that they would, their gonad development would progress fairly rapidly during the warm summer months, and they would most likely become ripe for spawning sometime in the autumn.   Such a spawning is documented by the September samples from Fortune Bay, but in the later samples from 1957 there is only little evidence of this group of herring.

The winter samples from Placentia Bay and Fortune Bay clearly indicate a considerable spawning in December and January, although the catches also included many herring which probably would spawn later in the year.

The samples from the spring and summer of 1958 do not always conform with those from the previous year in the same localities, but the general picture of different spawning groups is confirmed.

The 3 samples from the northeast coast of Newfoundland do not indicate any appreciable difference from the general situation on the south and west coasts with regard to maturity distribution and thus to spawning time.   Thus,

the present data give evidence of *an extreme spread in spawning time*, as was also indicated by the scale pattern. It is apparent that *some spawning herring may be found in Newfoundland waters in practically every month of the year*. The material does not suffice for an assessment of the relative importance of the seasons, but it would seem that *there is probably still a main spawning time in the spring*, in May and June, particularly on the west coast; *there is also some spawning in the autumn; and, at least on the south coast, a considerable winter spawning (December–January) takes place*.

DISCUSSION

The age and growth analysis of this material did not reveal anything which gives a direct clue to the great decline in the herring fishery. However, the investigations have disclosed one feature of the biology of these herring which needs further consideration. This is the extreme spread in spawning time, which, as we have seen, is probably a fact in all Newfoundland waters, but particularly prevalent on the south coast.

One of the earliest published records with reference to the spawning time of the Newfoundland herring is probably contained in a report on the herring fishery of 1890 by the superintendent of fisheries, Mr Adolph Nielsen, who states (Newfoundland Fish. Comm. 1891, p. 29): "that Fortune Bay and Placentia Bay are the principal resorts of the herring, and that when they appear in these localities in the autumn and winter they can be classified as 'full herring', and in the spring they become 'spent herring'."

In subsequent reports during the next 25 to 30 years there are numerous references to the general spring spawning habit of the herring, such as this (Newfoundland Dept. Marine and Fisheries 1916, Appendix p. 26): "As usual these fish resorted to their old haunts, in the shoal waters and muddy bottoms of the arms and bays at the usual time—the latter part of May and early June— in increased numbers for the purpose of spawning." This is also confirmed by Hjort (1915, p. 10) who briefly states: "The herring from the west coast of Newfoundland are spring spawners"; and Thompson (1931, p. 36) generally refers to the herring as spring spawners.

However, from some of the old reports it would appear that the spawning time was not always restricted to the spring months, but might in some years have included the month of July as well (Newfoundland Fish. Comm. 1892, p. 81; and Newfoundland Dept. Marine and Fisheries, 1907, Appendix p. 41).

From the investigations carried out by Tibbo (1956, p. 461) it appears that the spawning time in 1943 was from June 5 to 20 on the east coast, from May 24 to June 20 on the west coast, and from May 12 to June 5 on the south coast. Similarly, on the basis of his 1946–48 material, Tibbo (1957b, p. 160) concluded: "that spawning in some seasons, at least, is not completed until after the middle of June."

It would therefore appear that *all reports of observations prior to 1949 indicate that the Newfoundland herring were spring spawners.* The spawning may sometimes have been extended into the early part of the summer, but there is complete lack of evidence of any major departure from the "normal" spring spawning.

The first evidence of a change in spawning time was reported by Squires (1957), who in late September 1955 found pelagic herring larvae in the northern part of the Gulf of St. Lawrence. Mr Squires has kindly informed me that these larvae ranged from 5.2 to 19.1 mm in length, and in particular those caught near the Newfoundland coast (Sta. No. 10, 18 and 21) were quite small, not exceeding 12.0 mm. According to Bigelow and Schroeder (1953, p. 91) the herring is about 5–6 mm long at hatching. Thus, there can be no doubt that these herring larvae were derived from nearby spawning grounds, and at least some of them were spawned in Newfoundland waters.

A further observation of a departure in recent years from the usual spring spawning is reported by Tibbo (1959, p. 30), who, from summer experiments with drift nets at the south coast of Newfoundland in 1956 and 1957 concluded that: "the spawning season extended over a considerable portion of the summer."

The present study fully confirms these observations, and as we have seen, it also indicates a spawning in the winter as well as in the spring and autumn.

It seems quite improbable that the presence of significant numbers of herring spawning in the autumn and winter would have escaped notice at the time that systematic and detailed investigations of the Newfoundland herring were conducted by Tibbo. Consequently, we are led to conclude that *some time during the last 10–12 years* (perhaps gradually) *the Newfoundland herring, which for at least the previous 60 years had been spawning in the spring or early summer, changed their spawning habit so that now some spawning seems to occur in practically every month of the year.* This period coincides with the time of a grave decline in the herring fishery, but this in itself is not very surprising, because a change of this nature would affect the fishery in several ways.

Firstly, any change in spawning habits must be associated with changes in the usual migratory pattern and general distribution of the herring. In particular, because of the seasonal warming of the surface layer of water, a change from spring spawning to spawning later in the season would tend to move the herring into deeper waters and farther offshore when they come in to spawn.

The Newfoundland herring fishery is basically a shore fishery on spawning or pre-spawning concentrations. With the exception of a small purse-seine fishery on the west coast, the gears and vessels used are rather primitive and thus are not very versatile or adaptable to changes in the "normal" distribution and behaviour of the herring and are probably quite incapable of coping with a shift towards deeper waters farther offshore.

There is another aspect which may have been of even greater impact: the herring is a migratory species which changes habitat regularly with the season. Thus, the spawning grounds are usually different from the main feeding areas. In most herring populations there is a well defined and relatively short spawning

season and the whole bulk of the adult population recovers from spawning and undergoes every other phase of physiological development at about the same time of the year. Therefore, they tend to occur in concentrated bodies and undertake mass migrations to the various habitats as the seasons change.

Apparently in Newfoundland waters at present some herring are spawning while another group is in the main feeding stage and, as we have seen, all intermediate stages of development can be found at the same time, although with peaks at some particular times of the year.

The effect of this situation would be a general dispersion of the herring. Thus, on the south coast, where probably the spread in spawning time is most extreme, no large concentrations of herring comparable to those experienced prior to 1950, say, have been observed for many years and the traditional Fortune Bay fishery has ceased to exist. On the other hand, the herring accumulating in the Bay of Islands-Port au Port Bay area in late autumn appeared still to be mainly spring spawners and it is noticed that the purse seine fishery in this area remained uninterrupted until 1959.

Finally, one can raise the question of what effect such an unusual spread in spawning time as this study indicates may have on the recruitment, and thereby on the absolute size of the population. The fishermen complain about the herring being less abundant than previously, but this could merely be an effect of a change in availability and, in fact, no data exist on which any sound assessment of present, past or future population size can be founded. We can, therefore, only theorize about what effect a great spread in spawning time might have on the population size.

Since all known herring populations, and in particular those of great abundance, are characterized by one relatively short and well defined spawning period (perhaps in very rare cases two), one would be tempted to believe that this condition, as a result of "the survival of the fittest", is the one which provides the best recruitment and thus safeguards the survival of the species. If this holds true, it is to be expected that the change towards the great spread in spawning time has not only affected the availability of the Newfoundland herring, but has also caused a reduction of the population size. This would explain the increased growth rate mentioned previously, if we assume that the rate of growth is density dependent.

Considerable changes in spawning time are also known in other herring populations, and the idea that such changes have marked effects on the fishery is by no means new.

Thus, Devold (1959) suggests that the periodic disappearance of the Atlanto-Scandian herring from their usual spawning grounds off the Norwegian west coast is associated with an advancement of the spawning time of several months. The herring will then approach the Norwegian west coast too early to find suitable hydrographic conditions for spawning and proceed into Skagerak to spawn at the Norwegian Skagerak coast and the Swedish west coast.

The case of the Newfoundland herring is not a direct parallel, but it has

general interest and should be watched further.   Because of the present extremity
with regard to spawning conditions in this population, it might provide a rare
opportunity to study how a fish population is affected by factors of this nature.

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A Method for Preparing Glycerin-Stored Otoliths for Age Determination[1]

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ABSTRACT

Glycerin-preserved otoliths of burbot, *Lota lota*, often become opaque and difficult to age; they become readable if heated in glycerin for 10 minutes at 190°C, or for longer times at lower temperatures.

INTRODUCTION

SCALES, OTOLITHS, AND BONES or bony structures are frequently used for determining the age of freshwater fish. The burbot, *Lota lota*, has scales which are small, embedded, and scarcely noticeable, so the otoliths are used in age determinations. Under field conditions, it is often impractical to determine ages from fresh material and thus the otoliths must be held in a storage medium for an indefinite period. Otoliths from Heming Lake burbot were held in 50% glycerin in water and were found to be too opaque to allow adequate transmission of light even after grinding, and the annual growth rings were not clearly visible. Rather than discard the otoliths, an attempt was made to prepare them so that annual rings might become clear enough to permit age determination. Heating the otoliths caused browning which tended to accentuate the dark and light areas of growth and made age determination easier. The technique is presented here.

MATERIALS AND METHODS

Opaque otoliths preserved 4 months in 50% glycerin in water were washed in water and then wiped dry. The otoliths were first ground on a fine carborundum stone to facilitate light transmission. Reflected light was not used for examining otoliths in this experiment. They were then placed in porcelain crucibles. Some otoliths were covered with a drop of pure glycerin, others were not treated with glycerin, in order to see if the two methods differed.

The crucibles containing otoliths were heated in a drying oven at various temperatures ranging from 140°C to 200°C and were removed from the oven at time intervals from 5 minutes to 1 hour. A few samples were treated at temperatures above and below this range.

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RESULTS

The basic technique was discovered accidentally. Storage in glycerin was presumed to cause the opacity which often develops so it seemed logical that if the glycerin was driven off the annual rings might become more plainly visible. To expedite drying, the otoliths were heated in an oven rather than air-dried. No particular attention was given to the time of drying nor to the temperature; however, when the otolith was examined under a binocular microscope the annual rings were slightly more pronounced than they had been prior to drying. The improvement was at first attributed to the drying process which had browned the otolith through charring. Further experience suggested that perhaps the charring *per se* was not responsible for the differentiation of dark and light areas, but rather that the glycerin had not penetrated the otolith uniformly and had caused differential staining. Therefore a few otoliths were tested by placing them in a crucible containing glycerin and allowing them to cook in this medium. It was found that the otoliths browned much faster in glycerin and that the annual rings were much more pronounced (Fig. 1). The glycerin itself browned on
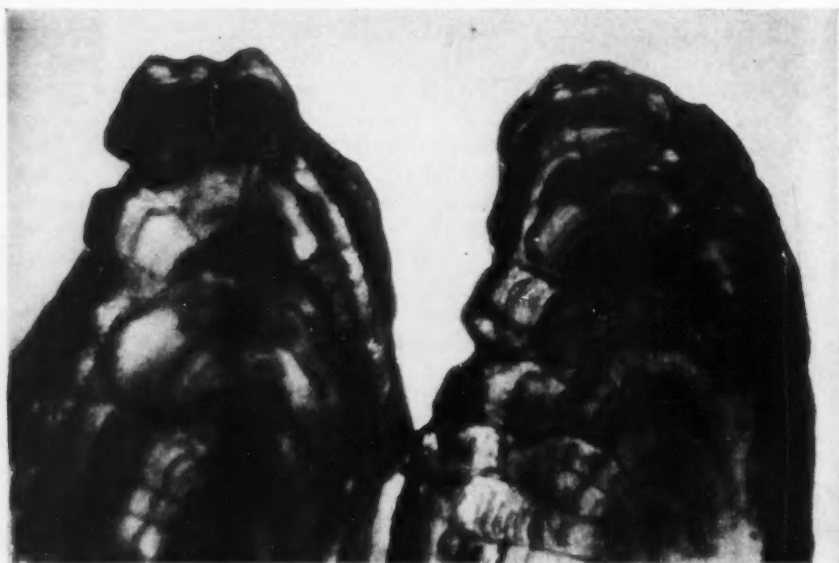
Fig. 1. Photomicrograph (×10) of a pair of otoliths by transmitted light. The effect of heating in glycerin is shown by the increased definition of the opaque areas on the right.

heating. As this treatment held promise of improving the quality of otoliths for age determinations, the method was tested under controlled temperature conditions. The results of the tests without and with glycerin are shown in Tables I and II, respectively.

Table I shows that otoliths stored in glycerin but washed and then heated without the addition of glycerin did become differentially browned.   Relatively high temperatures for prolonged periods of time were required before the annual rings were readily noticeable.   Too-high temperatures charred the otolith and

TABLE I. Time–temperature relationship for effects of heating burbot otoliths in an oven, without addition of glycerin. 0–No change; X–Slight browning but annual rings not clear; *–Brown in colour and annual rings outstanding; •–So dark that the annual ring was obscured.

Temp.	Time in minutes								
°C	5	10	15	20	25	30	35	40	45
110	0	0	0	0	0	0	0	0	0
125	0	0	0	0	0	0	0	0	0
140	0	0	0	0	0	0	0	0	0
155	0	0	0	0	0	0	0	0	0
170	0	0	0	0	0	0	X	X	X
185	0	0	X	X	X	X	X	X	*
200	0	0	X	X	X	X	X	*	*
225	0	X	•	•	•	•	•	•	•

rendered it useless.   Temperatures between 110°C and 155°C did not improve the readability of the otoliths and were classed as having had no effect.   At 170°C some browning effect was noted after 35 minutes, but the annual rings were still not very evident.   At 185°, after 45 minutes the annual rings were very clear. After 40 minutes at 200°C the annual rings were much more pronounced than at the previous temperatures.   At .225°C the otoliths were so charred after 15 minutes that they were useless for age determinations.

From Table II it is clearly evident that the addition of glycerin before heating improved the technique.   The otoliths browned more easily at lower

TABLE II. Time–temperature relationship for effects of heating burbot otoliths in an oven, with glycerin added to the crucible.   Symbols as in Table I.

Temp.	Time in minutes								
°C	5	10	15	20	25	30	35	40	45
155	0	0	0•	X	X	X	X	X	X
160	0	0	X	X	X	X	X	X	X
165	0	0	X	X	*	*	*	*	*
170	0	0	X	X	*	*	*	*	*
175	0	0	X	*	*	*	*	*	*
180	0	X	X	*	*	*	*	*	*
185	X	*	*	*	*	*	*	*	*
190	X	*	*	*	*	*	*	*	*
195	X	*	*	*	*	*	*	*	•

temperatures.   At 155°C some browning was noted after 15 minutes but continued exposure at this temperature did not differentiate the growth areas even after 45 minutes.   A rise of 5°C to 160°C made little difference in the appearance of the otolith.   At a temperature of 165°C however, the annual rings were clearly visible after 25 minutes exposure.   Further increases in temperature resulted in a reduction in the time required to produce the desired effect, for example, over the temperature range 185° to 195°C the annual rings stood out after only 10 minutes in the oven.

DISCUSSION

Burbot otoliths stored in glycerin may become opaque, resulting in the disappearance of the annual rings.   Heating as described above either chars the otolith differentially or causes the glycerin to brown, the effect of which is noticed more in the translucent rings.

Whether it is the effect of heating *per se* or the addition of glycerin in combination with the heat that produces the end results is still in doubt.   However, this method has proved of considerable use, for the junior author has treated (with remarkable effectiveness) otoliths removed in 1959 and stored for at least 4 months. This technique did not require a great deal of preparation, and the final results justified the time required as it was possible to assign ages to otoliths that were unreadable.   Other species of fish, in which the otoliths are large and thick, may react differently.   The burbot otoliths used in this experiment were not thick, having been taken from fish the largest of which was 21 inches (53 cm) in length.

Phytoplankton of the *Calanus* Expeditions in Hudson Bay, 1953 and 1954[1]

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CONTENTS

ABSTRACT

Phytoplankton samples, collected in 1953 and 1954 by the *Calanus* expeditions, were examined by the quantitative sedimentation method in an attempt to determine the ecological aspects of phytoplankton production in Hudson Bay and Strait. During the period July to September of both years, water temperature data, and salinity, oxygen and quantitative phytoplankton samples were collected at the surface and from depths of 10, 25, 50 and 100 metres. Numerically, the most abundant, heterogeneous phytoplankton populations were found in the mouth of Hudson Bay. The lower production of phytoplankton in the surface layer can be explained by the greater amplitude of temperature and salinity, dependent upon ice conditions and surface wind drift. The most productive layer was at a depth of 10 m. Large phytoplankton populations in waters supersaturated with oxygen were still found at 25 m, indicating light conditions favourable for photosynthesis. The relatively high plankton production in the area joining Hudson Bay and Hudson Strait is probably due to the hydrographic structure and the supply of nutrients resulting from the mixing of water masses which originate in other geographical areas. The preponderance of diatoms over flagellated groups, which is more marked in Hudson Strait than in Hudson Bay,

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is typical for the arctic.   The composition of phytoplankton in these areas shows a great similarity
in the main to that found on both sides of the Atlantic.   Apart from locally produced plankton
populations, there is a population exchange which follows water movements.   To supplement
the meagreness of existing taxonomic descriptions, attention is here focussed on the identification
of plankters and their individual importance in the general ecology of the phytoplankton.

INTRODUCTION

DURING THE SUMMERS OF 1953 AND 1954, the M.V. *Calanus* investigations of the
Fisheries Research Board of Canada were carried out in northern Hudson Bay
and western Hudson Strait.   Part of the scientific programme consisted of
phytoplankton sampling, the results of which are reported here.

Sampling was done during the periods July 21 to 30, August 3 to 17 and
September 2 to 16 in 1953, and July 22 to 24, August 3 to 21 and September
4 to 16 in 1954.   Station locations, shown in Fig. 1, are described by Grainger
and Dunbar (1956).
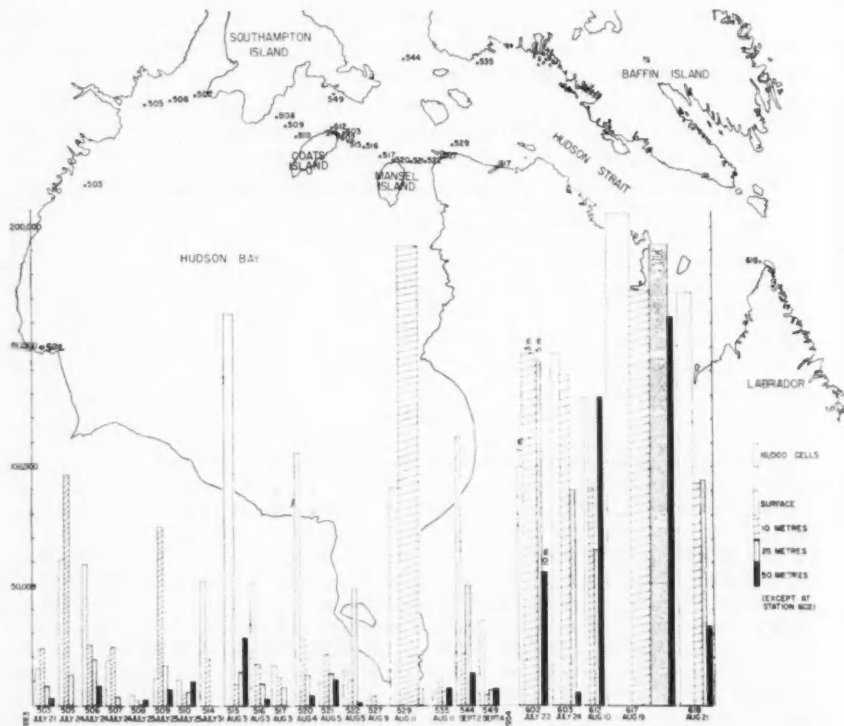
FIG. 1. Histogram-map showing vertical and horizontal distribution of diatoms and dino-
flagellates in Hudson Bay and Hudson Strait.   Numbers on the left scale refer to single columns.
Lines at the top of the histogram bars show the number of columns per bar.

Seven areas, where quantitative and qualitative plankton stations were occupied, have been distinguished in northern Hudson Bay and Hudson Strait.

1. The western Hudson Bay coastal area, including stations 502, 503, 551, 553 and 555.

2. The area between Chesterfield Inlet and Southampton Island (Cape Kendall), including stations 505, 506 and 507.

3. The northern parts of Hudson Bay, including stations 508, 509, 510, 512, 549 and 612, located in Fisher and Evans Straits and south Foxe Channel.

4. The area between Coats and Mansel Islands, including stations 515, 516, 517 and 520.

5. The area between Cape Wolstenholme (northwest Quebec) and Mansel Island, including stations 521, 522, 527 and 529.

6. The west Hudson Strait area, including stations 531 and 535, and the Sugluk and Nuvuk stations 526 and 617.

7. The east end of Hudson Strait, including station 618.

PREVIOUS INVESTIGATIONS

The history of phytoplankton investigations in the Canadian eastern arctic is brief. The only previous work in Hudson Bay was done by Davidson (1931) who made quantitative and qualitative studies on phytoplankton collected with fine silk nets by the trawler *Loubyrne* in August and September of 1930. A series of collections was made by Polunin (1934) in Ungava Bay, at Akpatok Island.

The eastern arctic waters have been investigated by various foreign expeditions. The Nares expedition (1875–76) to Ellesmere Island and north Greenland collected the first dinoflagellates, reported by Dickie (1878), and diatoms, described by Cleve (1883). The ship *Michael Sars* in 1924, with Gran on board, collected plankton from five stations in Davis Strait (Seidenfaden, 1947). Much information on the ecology and taxonomy of arctic phytoplankton, including thecate dinoflagellates, was assembled by the Godthaab Expedition (Grøntved and Seidenfaden, 1938).

These are the more important contributions to our knowledge of the phytoplankton in eastern Canadian arctic waters. The collective papers of Whelden (1947) on algae, Seidenfaden (1947) on marine phytoplankton, Ross (1947) on freshwater diatoms and Holmes (1956) on central Labrador Sea collections, complete the list of literature. The Labrador Sea phytoplankton was found to be neither strictly arctic, boreal nor temperate, and neither completely oceanic nor neritic. Since this vast area is still largely unexplored for phytoplankton, our knowledge of the composition, distribution and production of plankton remains scant. It is not only of pure theoretical scientific interest but also a practical necessity to understand the general biological economy of the arctic.

METHODS

Water samples, collected in Nansen reversing water bottles, and preserved in 5% neutral formalin, were used for quantitative phytoplankton studies. They were stored in approximately 170-ml glass bottles with bakelite screw caps. Before sedimentation of the samples, each sample was shaken 20 times to ensure even mixing of plankton. It was found that too energetic shaking of the bottle containing plankton breaks the longer chains of *Thalassiosira* and *Chaetoceros* into small fragments, making counting and identification tedious. The Utermöhl inverted microscope was used for quantitative estimations, with the prismatic ocular ×8 being used for counting. Objectives of 10, 25 and 40 powers were used according to the frequency of species and their size. The larger, less numerous forms were examined, with objective ×10, in a 25-ml cylinder; smaller, more numerous forms, with objectives ×25 or ×40, in 10- or 5-ml cylinders. Samples containing a moderate number of species and small populations of so-called gamma or μ-plankton were examined in 25-ml cylinders. In a few instances the original water was diluted with distilled water 1 to 1, then examined. Rare species and those difficult to identify were isolated from the cylinders with a pipette, then observed under the high power of a compound microscope. Quantitative samples were usually examined after 15 or 20 hours of settling. Plankton nets of numbers 20 and 5 silk mesh, hauled horizontally and vertically, were used for qualitative studies. Diatoms of net hauls were washed in distilled water, boiled with acid, then washed again, for making temporary preparations. All drawings were made with *camera lucida*. Front phase illumination was also used for taxonomic identification of dinoflagellates and other forms. All cells in chains were individually counted.

HYDROGRAPHIC CONDITIONS

Hydrographic conditions in northern Hudson Bay and western Hudson Strait have been described most recently by Dunbar (1958) and Campbell (1959), the former using *Calanus* material collected from stations discussed here. While the most northwesterly stations show the influence of arctic water flowing southward into Hudson Bay through Roes Welcome Sound, those of northeast Hudson Bay and west Hudson Strait are in a region showing complex hydrographic conditions, where arctic waters from Foxe Channel and warmer waters from southern Hudson Bay converge. Present data from the area under consideration do not permit a real assessment of the relation of the phytoplankton to temperature, since no continuous records are available from any one location. It appears however that phytoplankton populations are greater in those areas where various water masses mix.

Ice is a factor of extreme importance, and a highly variable one from year to year. The holophytic plant societies especially are affected by ice cover influencing light, salinity and temperature conditions, and diatom spring maxima may be delayed for many weeks by a persistent ice cover (Braarud and Hope,

1952). Open leads in the ice cover are probably of considerable importance in allowing sufficient illumination for photosynthesis in very local areas.

The physiological effect of changing salinities in the sea cannot be separated from the influence of temperature acting simultaneously. Various dinoflagellates have their own optima of growth and development as far as salinities are concerned (Braarud, 1951). Surface waters of the studied area, covered with melting ice in summer and autumn, are especially exposed to rapid temperature and salinity changes. Such conditions do not favour metabolic activities of plankton, producing osmotic barriers for the typical euryhaline species. Lower salinities close to the under surface of the ice are found when ice melts; when it is solid salinities are higher, and allow rich growth of the diatom film. Observations of the author during the H.M.C.S. *Labrador* cruise in 1956 show that green-brown films of diatoms occurred under the ice turned up by the ice-breaker around Baffin Island. Special observations carried out on the naked genera of dino-flagellates show that some genera, for example *Gymnodinium*, *Gyrodinium*, *Amphidinium* and *Massartia*, are rare in the vicinity of ice while they occur more frequently in the leads. Some typical marine species show definite resistance to varying salinities in the coastal area. *Goniaulax tamarensis*, according to the author's observations, is specially adapted to changing salinities by immediate production of thin-membraned cysts. *Ceratium* species, when swept into brackish lagoons, become strongly plasmolized or reject their flagella, or the whole proto-plasm escapes from the cell-membrane, as observed by the present writer in the Point Barrow area of Alaska. It is possible that freshwater *Dinobryon* species have great adaptability to marine conditions since large populations of this chrysomonad, with cysts, were found by the author in the sea in good condition. *Scenedesmus*, *Oocystis* and *Ankistrodesmus*, swept from ice pools, perish after a few days in the sea.

The oxygen data collected indicate well-oxygenated surface and even deeper layers, where phytoplankton was found in sufficient quantities to cause it. The surface-to-25-metre layer shows supersaturation of oxygen at stations 502, 503, 505, 508, 510, 520 and 527. It is to a certain degree in agreement with Nutt and Coachman's (1956) observations on oxygen distribution in Hebron Fjord, Labrador. Subsaturated surface water occurred in 1953 at stations 517 and 544, in 1954 at stations 502, 612 and 617. This is not understood since large diatom populations were found at these stations. At 25 metres only five subsaturated samples were recorded. At 50 m there was slight supersaturation at nine stations.

DETRITUS

Special emphasis has been given to leptopel in the sea, to its importance in biological cycles involving the release of organic nitrogen and phosphorus by bacteria and the reassimilation of these soluble molecules by phytoplankton, and to the amounts of leptopel and populations of living communities (Goldberg, Baker and Fox, 1952; Fox, Isaacs and Corcoran, 1952). Identification of water

masses by their suspended particles was carried out by Atkins and Jenkins (1955), Burt (1955) and Gran and Braarud (1935), who found large concentrations of detritus in quantitative samples from the Gulf of Maine, where it affects the phytoplankton production.

In the present collection detritus occurred in many stations in sedimentation cylinders in the form of amorphous organic particles or as long fibres derived from various plant tissues.   The largest concentrations of detritus were observed in the neritic stations 527, 535, 529, 506, 507, 508, 612 and 618, which were located in shallow water.   At some detritus was distributed evenly from the surface to the bottom, while at station 509 little detritus was found at the surface, but a dense concentration occurred at 10 metres depth.   At station 508 large concentrations were found at 25 m and 80 m, while the top samples contained only small quantities of detritus.

Phytoplankton samples containing large concentrations of detritus had poor populations and reduced numbers of species in contrast with samples with no detritus.

The main detritus supply in the arctic comes from the sea floor deposits, rivers and lakes, and is swept from the land by wind and rain into the sea.   Huge quantities of detritus are found in the arctic ice.   During melting of the sea ice, arctic waters show reduced transparency because of the ice-detritus.   Turbulent or stormy waters contain both mineral and organic detritus.   The heavier mineral particles after a few days sink and remain at the bottom, while lighter organic detritus may remain longer in suspension.   The particles of detritus serve as attachment surfaces for bacteria, which affect the physiological metabolism of the phytoplankton.   According to Burkholder and Burkholder (1956), suspended particles are important in the vitamin nutrition of the sea and bacteria are significant producers and carriers of vitamin B_{12} in the marine environment.

GENERAL FEATURES OF THE PHYTOPLANKTON

The present list of phytoplankton species includes 92 diatoms, which with Polunin's (1934) records makes a total of 114 species.   Dinoflagellates are represented by 91 species, a number which may be increased still further by inclusion of the "naked" forms.   Two species of Coccolithophoridineae, 3 Silicoflagellata, 3 Chrysomonadineae, 2 Heterocontatae, 5 Chlorophyceae, 3 Desmidiaceae, 4 Cyanophyceae, 22 Ciliata and some unidentified Flagellata, including 6 types of cysts of unknown origin, complete the list.

Hudson Bay and Hudson Strait show a great similarity to both sides of the Atlantic, in terms of phytoplankton species, as seen from the work of Gran (1905, 1919), Gran and Braarud (1935) and Gaarder (1954).   A small number of Hudson Bay species may represent relicts from a warmer period.   According to Dunbar (1956), Hudson Bay, although definitely outside the subarctic waters and showing many of the characteristics of the arctic zone, should be placed in a category by itself.   This is because of the high temperature and low salinity in the upper layers in summer (as high as 10°C and as low as 23‰ salinity), and because of the

preservation of warmer water relicts such as capelin and the calanoid *Acartia clausi.*

Since phytoplankton distribution is controlled also by water currents, Atlantic and northern arctic plankton find their way into Hudson Bay. The occasional visitor from warmer seas once introduced may survive under arctic conditions, but probably only in very small numbers, because of light deficiency and low temperature. Three species, *Pterosperma reticulatum,* known from Florida, the Red Sea and Newfoundland, *P. ovum,* from salps in the South Seas and from Helgoland, and *Rhabdosphera spinosa,* from the northwest African coast and the Azores, represent possible warm water elements introduced in recent times.

The pattern of physiological adaptation of the euryhaline warm water element and freshwater autotrophs to the marine habitat is obscure. Different degrees of salinity–temperature tolerance have been specific in some arctic and cosmopolitan phytoplankton species (Smayda, 1958). The occurrence of large populations of the freshwater *Dinobryon pellucidum* and *D. balticum* in high salinities in the deeper layers of the Arctic Ocean and in Foxe Basin (author's unpublished data) indicates that freshwater forms are favoured by the low temperatures of the arctic. It is in agreement with experiments and field observations made by Doty and Newhouse (1954) that stenohaline and metahaline forms tolerate better higher salinities in low temperatures. The slow decrease of surface salinities during the ice melting period and their increase during the time of open water is thought also to be an advantageous factor in the adaptation of some freshwater species to the arctic environment.

SPECIFIC FEATURES OF THE PHYTOPLANKTON IN HUDSON BAY IN 1953*

Station 502. The horizontal net tow contained 71 species in which diatoms dominate. *Melosira islandica, Fragillaria gracillima, Botryococcus brauni, Pediastrum, Scenedesmus,* Desmidiaceae and Cyanophyceae show a strong influence of brackish freshwater elements, although the station was situated five miles from the coast. The dinoflagellates represented were *Ceratium hirundinella, Peridinium inconspicuum* and rare forms. It is remarkable that many freshwater Rotatoria also occurred in this haul; the typical lake inhabitant *Notholca longispina* and other freshwater species of Rotatoria were common. There were only 36 species at this station, mostly of the tycho-pelagic element.

Station 503. The net samples consisted of 67 species, both diatoms and dinoflagellates. There were no special features except for the occurrence of more diatoms at 10 m than at the surface.

Station 521. This station provided 31 species in vertical and horizontal hauls, mostly neritic and brackish species.

Station 553 (net only). This provided 28 species and showed great similarity to the previous station.

*Copies of the raw data can be obtained upon request to the author.

Stations 505, 506 and 507. These show evident dominance of *Chaetoceros compressus*, *Ch. concavicornis*, *Nitzschia closterium*, *N. seriata*, *Fragillaria nana* and other planktonic diatoms, descending to 25 m in moderate quantities. *Rhizosolenia styliformis* increased from the surface to reach 3,600 cells/l at 25 m. *Goniaulax tamarensis* was relatively numerous from the surface to 10 m, with populations of 7,680 and 8,800 cells/l. Unknown spherical forms of holozoic flagellates appeared in large numbers (41,000/l) at 10 m. *Ceratium arcticum* occurred as 1,040 cells/l at the surface, *Exuviella* sp. in small quantity only at 10 m.

Station 506. This shows a typical marine composition of species, taken in large number as deep as 50 m. Unusually great numbers of coccolithophorids (631,000), *Bodo* sp. (29,000) and a large number of unidentified flagellates occurred. *Scenedesmus* was found at 50 m only, as 2,000 cells/l.

Station 507 showed conditions similar to those at station 506.

Station 508 had poorer populations of similar composition to those at station 507.

Station 509. This produced abundant plankton, similar in composition to the stations above, with diatoms dominant. *Chaetoceros debilis* at 10 m reached a maximum of 61,560 cells/l, at 25 m showed only 3,600. *Cyclotella* sp. and *Melosira* sp. were found in relatively large quantity from the surface to 100 m. *Thalassiosira rotula* occurred as 46,000 cells/l at 25 m.

Station 510. This showed mostly diatoms, as deep as 100 m. *Chaetoceros karianus*, *Ch. concavicornis*, *Ch. atlanticus* and *Ch. debilis* were represented from the surface to 50 m by a few thousand cells per litre.

Station 512 (net tow) yielded 26 species among which *Ceratium longipes* was dominant and the littoral element common.

Station 514 showed reduced plankton, mostly diatoms among which *Chaetoceros compressus* reached 24,800, *Achnantes taeniata* 3,700 and *Thalassiosira rotula* 7,800 cells/l. There were 36 species in all, mostly diatoms and dino-flagellates.

Station 515. This showed moderately rich plankton with highest production at 25 m, mostly *Chaetoceros*, with *Thalassiosira rotula*. *Chaetoceros compressus* occurred unusually at 50 m, as 25,000 cells/l. This station showed typical pelagic communities of the area.

Station 516. Here the dominant elements were *Chaetoceros*, with 20,800 cells of *Ch. compressus* at the surface. *Thalassiosira gravida* reached 5,940 cells/l at 25 and 50 m.

Station 517. Plankton at the surface here was much reduced, and it occurred more abundantly at 10 and 25 m, where *Thalassiosira* was present as 20,400 and 5,200 cells and *Chaetoceros debilis* as 1,000 cells/l at 25 m. Freshwater and neritic elements were represented by *Fragillaria crotonensis*, Desmidiaceae, and *Coscinodiscus oculis viridis*, the latter as 1,240 cells/l at 25 m.

Station 520. Large numbers of *Pontosphera* and unidentified flagellates occurred here—up to 100,000 cells/l. There was a maximum of *Chaetoceros* at 25 m, with *Ch. debilis* as 1,800 cells and others in relatively small numbers. In the net haul there were 59 species.

Station 521.   This showed more evenly distributed plankton, the maxima however occurring in the deeper layers.

Station 522.   This was remarkable in that numerical increase started at 10 m and reached, in *Chaetoceros debilis*, 200 at 10 m, 1,200 at 25 m, and 35,420 cells/l at 50 m.   *Nitzschia closterium* was observed at its surface maximum at this station, with 6,220 cells/l.

Station 526 (net tow).   There were nine species in the vertical haul, and 14 in the horizontal.   Typical oligotrophic conditions existed.

Station 527.   Poor plankton conditions prevailed here, with only 16 species being found in the sedimentation cylinders and 26, mostly neritic species, in the horizontal net haul.

Station 528 (net tow).   Poor plankton, neritic and benthic forms, occurred.

Station 529.   *Chaetoceros* plankton was characteristic here, with *Ch. lorenzianus* at its maximum of 27,160 cells/l at 10 m, and a population of diatoms and coccolithophorids at the surface of 183,500/l, a maximum at 10 metres of 389,000 cells/l, and a sharp decrease at 25 m.

Station 535.   A small number of species occurred here in comparison with station 529.   There were 48 species in the net haul.

Station 531.   The horizontal net haul contained 57 species, of heterogeneous populations of neritic and pelagic diatoms and dinoflagellates.

Station 540.   There were 35 species in the horizontal net haul, with a dominant *Chaetoceros* population and *Achnantes taeniata*.   Dinoflagellates were abundant.

Station 544.   This was one of the most productive stations, in spite of the late date.   The diatom populations of *Coscinodiscus concinnus* and *Cyclotella* sp. were at their maximum, and the *Chaetoceros* group was abundant at the surface and deeper.   *Nitzschia closterium* was present as 18,980, *Fragillaria nana* as 11,400 cells/l.   *Leptocylindrus danicus*, found usually in small quantities, showed a population of 4,900 cells at 25 m, *Amphidinium* as 16,000, *Goniaulax tamarensis* as 11,000 and *Thalassiosira gravida* as 2,400/l.   The larger population of the transition area between Foxe Channel and Hudson Strait is evident in this station, and it is also probable that these waters show a later start in their plankton increase because of inflowing arctic water bringing lower temperatures and ice. The vertical net haul at station 544 contained 32 species, the horizontal one 53 species.   Various unidentified cysts were also observed.

SPECIFIC FEATURES OF THE PHYTOPLANKTON IN HUDSON BAY AND STRAIT IN 1954

Station 602.   This station showed an abundant phytoplankton population, especially in the diatoms of pelagic origin.   The maximum of 78,500 cells of *Chaetoceros debilis* and 210,600 *Thalassiosira* per litre was found at 3 m; there were 13,080 cells of *Thalassiosira gravida* at 15 m, 20,000 *Fragillaria* at the surface, 24,600 *Chaetoceros compressus* and 3,400 *Thalassionema nitzschioides* at 15 m, and 1,200 *Peridinium subcurvipes* at the surface.   The vertical net haul contained 13 species only.

Station 603.   This was still more productive, although its largest number of species was limited to the 10-metre layer: *Chaetoceros concavicornis* (12,000), *Ch. compressus* (22,400), *Ch. decipiens* (31,600 cells /l).   *Ch. debilis* reached its maximum for the year with 120,000 cells at 10 m.   *Ch. furcellatus* showed 100,000 at the surface, *Ch. karianus* 60,000 at 10 m, *Thalassiosira nordenskjöldi* 19,200, and *Th. rotula* 39,600 at 10 m.   Freshwater species occurred as 30,000 cells/l.

Station 612.   This station showed a peculiar distribution of dispersed phytoplankton populations from the surface to 100 m.   At 50 m, cell numbers were: *Chaetoceros compressus* (59,800), *Ch. debilis* (34,200), *Ch. furcellatus* (48,000), *Ch. lorenzianus* (38,200).   *Dinobryon balticum* and *D. pellucidum* reached 34,000/l, again showing freshwater influence.   There were only 18 species in the vertical net haul, 42 and 51 species in two horizontal net hauls.   Diatoms dominated in all collections.

Station 617.   This showed a very rich plankton from the surface to 50 m. The greatest numbers were found here of *Chaetoceros compressus* (1,325,000 cells at 10 m), *Ch. furcellatus* (320,000 at 25 m), *Ch. socialis* (910,000 at 25 m), *Fragillaria nana* (68,000 at 25 m).   Rare elsewhere, *Eucampia zodiacus* was found at its maximum of 30,000 cells/l.   *Thalassiosira gravida* showed 98,000 at the surface, and 102,000 cells/l at 25 m.   Of *Th. rotula* there were 55,000 cells/l at 10 m.

Station 618.   This, the most easterly station discussed here, was near the east end of Hudson Strait.   Populations were smaller than at station 617 because of the pelagic nature of the station.   *Chaetoceros compressus* and *Ch. socialis* were taken as 353,000 cells/l at the surface.

The six phytoplankton stations located on the north side of Coats Island, in Sugluk Bay and 17 miles west of Burwell, in Ungava Bay, indicate great differences as far as composition and size of phytoplankton populations are concerned.   The main species are *Chaetoceros compressus*, *Ch. furcellatus*, *Ch. lorenzianus*, *Ch. karianus* and *Ch. decipiens*, associated with *Thalassiosira gravida*, *Th. rotula* and *Fragillaria* populations.

It seems evident, comparing the 1953 and 1954 phytoplankton, that the Hudson Strait area is more fertile and productive than Hudson Bay, although the latter cannot as yet be well estimated because there are collections from only a few stations dispersed over a wide area.   In July 1956 the writer observed a diatom bloom at the surface in the middle of Hudson Strait.   Very dense brown patches covering a large area of several miles were observed from the bridge of H.M.C.S. *Labrador*.

QUANTITATIVE DISTRIBUTION OF DIATOMS AND DINOFLAGELLATES

The histogram in Fig. 1 shows quantitative distribution of diatoms and dinoflagellates found at the surface, 10, 25 and 50 m, in Hudson Bay (1953) and Hudson Strait (1954).   It is obvious that phytoplankton populations, represented by the number of cells per litre of sea water, increase greatly when one moves from Hudson Bay towards Hudson Strait.   It should be considered however that

the following factors may affect each local production: time of the sampling, distance from the coast, ice and salinity conditions, and type of the water-masses and their geographical origin. Since a single plankton station can be compared with a "single photo shot" cut from a 12-month film, our impression is greatly limited. It is therefore supposed that the production maxima are much higher in both areas, but that they were missed since they usually are of short duration. It is possible that maxima of diatoms occurred at the end of May and middle of June in Hudson Bay and later in Hudson Strait. The surface populations in June and July are small in the majority of stations as a result of lowered salinities; when salinities become higher in August and September production at the surface increases greatly. More stabilized salinity and optimal light conditions favour growth of photosynthesizing organisms, showing the highest level of vertical production. The 25-metre depth shows a decrease of plankton populations. The high number of diatoms at the 25- and 50-metre levels may represent "sinking populations" which as observed in several cases possess cysts of specific gravity greater than that of sea water. Cyst formation takes place in various species at different times of the vegetative season. Both pelagic and neritic diatoms could be carried down and up by vertical currents. Coccolithineae and other insignificant producers of biomass were not included in the histogram.

GRAZING

The main bulk of primary food in the arctic seas consists of diatoms. "The standing crop of plants at any time is the resultant balance between the rate at which they have been produced and the rate at which they have been eaten", according to Harvey (1950). This problem has attracted much attention and has been discussed from various points of view, by Fleming (1939), Riley (1946, 1953), Riley and Bumpus (1946), and others. It is generally simplified by most of the authors who put all phytoplankton in one group, and all zooplankton in the opposite one. Though zooplankton represents the main consumer of phytoplankton, reducing greatly its quantity, there are other feeders within the marine food chain represented by various taxonomic groups of holozoic and holophytic flagellates. It is of biological interest to distinguish all existing links acting in the grazing of plankton. The following groups of feeders are distinguished by the present writer:

1. Choanoflagellata, Bodonidae and many other heterophytic flagellate-ingesting bacteria, and Coccolithophoridineae.

2. Holozoic flagellates which ingest holophytic species.

3. Holophytic flagellates which ingest both holophytic and holozoic forms including copepod eggs and ciliates.

4. Ciliates, including Tinntinnidae, which feed upon diatoms and flagellates.

5. Zooplankton, which are the most efficient grazers, representing the main consumers of plants in seas.

The grazing rate of copepods is enormous. Estimates from biomass and pigment show its maximum in July and August in Greenland by Digby (1953). Harvey (1937) found 74 to 94 ml of food-bearing water per *Calanus* to be swept clear in 24 hours. Gauld (1951) found that about 70 ml per 24 hours were swept clear of *Chlamydomonas* cells. The range was from 250,000 to 2,000,000 cells.

The mean number of ciliates per litre at each station in Hudson Bay and Strait is shown in Table I. There are represented 22 species of ciliates among

TABLE I. Number of ciliates (averaged according to the number of depths sampled) taken at various stations in Hudson Bay and Hudson Strait.

Station No.	No. of ciliates	Station No.	No. of ciliates
503	350	521	615
505	420	522	1,152
506	448	527	133
507	160	529	173
508	260	535	165
509	100	544	288
510	540	549	350
514	500	602	288
515	283	603	255
516	144	612	272
517	10	617	208
520	320	618	132

which *Mezodinium*, *Laboea* and *Lohmanniella* are most common. It is supposed that these are able to make vertical migrations in search of food, because of their well developed ciliary apparatus. High numbers of ciliates are not always associated with large populations of phytoplankton which the grazers can rapidly reduce. The maximum of 1,152 ciliates at station 522 was exceptional; at most stations there were between 200 and 600 individuals per litre. Such populations can rapidly reduce the plant population.

Holophytic species of *Peridinium gargantua* (Biecheler, 1952) are voracious, and are able to ingest holophytic and holozoic flagellates. *Gyrodinium pavillardi* (Biecheler) is able to attack *Strombidium* larger than itself. Phagocytosis was observed by the author in *Massartia*, *Amphidinium* and many other genera, diatoms and various heterotrophic flagellates being captured by them. *Polykrikos* sp. is able to ingest eggs of copepods, various peridineae and flagellates. Many of the organisms have selected species upon which they feed. At Woods Hole (Eel Pond) *Prorocentrum redfieldi* was devoured mostly by Tinntinnidae (author's unpublished data). Copepods in the Point Barrow area of Alaska contained mostly dinoflagellates, while in Foxe Basin they appeared to feed exclusively upon diatoms (author's unpublished data).

QUANTITATIVE DISTRIBUTION AND ECOLOGY OF THE DIATOM SPECIES

Diatoms are the principal food producers of the arctic, where the flagellated organisms are only of minor importance.   Occurrence of the diatom species is discussed below.

Achnantes taeniata Grun.   Found at stations 502, 540, 555, 602 and 603, usually in small numbers in late July 1953 (2,400 to 3,700 cells/l).   A truly arctic species, it is abundant among the ice floes of the Arctic Ocean and in the Baltic.

Amphiprora hyperborea Grun.   Occasionally found in small numbers in both areas.   Arctic, neritic.

Asterionella gracillima Grun.   A freshwater species, found only at station 502, at the surface, and at station 540 in the net sample.

Asterionella kariana Grun.   Rare in horizontal and vertical net hauls at stations 514, 535, 555, 602, 603, 612 and 226.   This arctic neritic species was found in small quantities in the Bay of Fundy from April to September by Gran and Braarud (1935).

Atthea decora West.   Taken in a net sample from station 514, this pretty benthic diatom was attached to a grain of sand as a single cell.

Asteromphalus robustus Castr.   Present in net hauls at stations 540, 553, 555 and 226 in small numbers.   Arctic.

Biddulphia aurita (Lyngb.) Brebisson and Godey.   Common in small quantities in net and quantitative samples.   As a littoral form it indicates the influence of coastal environment.   Found at stations 514, 528, 531, 540, 602, 603, 612, only in horizontal net hauls.   Widely distributed in the arctic coastal area.

Cocconeis placentula Ehrenb. and *Cocconeis* sp.   Found attached to *Coscinodiscus concinnus* at station 502, it represents the epiphytic, littoral element.

Chaetoceros atlanticus Cleve.   This oceanic species is widely dispersed over the Hudson Bay area and is also common in Hudson Strait at the majority of stations.   The vertical occurrence shows that this pelagic organism forms autochthonous populations within the euphotic zone in the middle of Hudson Bay where the closed cyclonic water circulation exists.   *Ch. atlanticus* disappears or is represented by very reduced populations within the littoral area.   The maximum of 6,400 cells was found at 25 m at station 521, and populations were recorded from a few hundred cells to several thousand cells per litre.   Occurrence from the surface to the deepest water sampled was found at stations 544, 602 and 612.   It is a typical northern oceanic species, arctic and boreal, found occasionally as far south as California.   Davidson (1931) found it spread over the whole of Hudson Bay.

Chaetoceros concavicornis Mang.   This pelagic species is distributed in small quantities in the far northern waters of Ellesmere, Baffin and Devon Islands. It was observed by Braarud (1935) in Denmark Strait.   In the Hudson Bay and Strait area it was widely distributed, represented by small populations within the coastal areas and by larger populations offshore.   Its maxima were usually from 10 to 25 m, but down to 50 m at stations 509, 510 and 549, suggesting by this the probable introduction to Hudson Bay of a large population of arctic origin.   The maximum of 12,000 cells/l was recorded at station 506.   Large populations, continuous in vertical distribution, occurred at all stations in Hudson Strait.   It is an oceanic, arctic and boreal form.

Chaetoceros convolutus Castr.   This was found mostly in the net hauls.   It is an oceanic, arctic and boreal form, observed in small numbers at 11 stations in Hudson Bay and Strait.

Chaetoceros constrictus Gran.   This occurred mostly in net samples at stations 502, 503, 528, 531, 540 and 549, although according to Grøntved and Seidenfaden (1938) it is confined to temperate waters.   It has also been found by the author at the mouth of Hudson Strait, in autumn.

Chaetoceros compressus Lauder.   This is widely dispersed over the area, and was common in net hauls at stations 502, 513, 520, 526, 535, 549, 551, 553, 603 and 612.   It becomes more numerous as one moves from Hudson Bay to Hudson Strait, and in Hudson Strait functions as an important producer of biomass.   Counts at the surface varied from 3,620 to 325,000 cells/l.   Common throughout the whole collecting period, its maximum numbers occurred in late summer.

Chaetoceros curvisetus Cl.   This was found sporadically in Hudson Bay, at stations 505 at the surface (3,500 cells/l) and 544 (20,000 cells).   It is an important species in subtemperate waters.

Chaetoceros diadema (Ehrenb.) Gran.   Common in horizontal net samples at stations 502, 503, 514, 520, 528, 531, 535 and 603.   It was not found in the sedimentation cylinders.   It is possible that the maximum in Hudson Bay occurs in early spring, before sampling was begun.   This neritic species is common all over the arctic.

Chaetoceros decipiens Cleve.   Common in both areas in the net plankton, it occurred at station 514 at the surface as 3,640 cells/l.   In 1954, at station 602, 8,000 cells/l were counted at the surface, and 1,480 at 3 m.   The maximum count was 31,600 cells at station 603, where there were 12,000 at 10 m and 4,800 cells at 25 m.   A large, isolated population of 28,600 cells/l was found at 10 m at station 617.   It occurred often in the net samples.   It is remarkable that in the Gulf of Maine the highest count recorded by Gran and Braarud (1935) was 3,600 cells/l, in August.

Chaetoceros debilis Cleve.   The most common neritic *Chaetoceros* species in the area, it is an important component of the phytoplankton in northern European waters, where it is dominant in early spring.   It was found in most

horizontal net hauls in Hudson Bay. According to Seidenfaden (1947) this boreal species is locally common in August in the Canadian eastern arctic, especially near the coast. Greater populations were found between Coats and Mansel Islands (stations 515, 516, 517 and 520) than in the inner part of Hudson Bay. At station 520, 12,880 cells/l occurred at 10 m, surface numbers being smaller, probably having been grazed or moved by surface wind drift. The large populations at 3 m at station 602 (78,500 cells), at the surface at station 617 (82,400 cells), and at the surface of station 618 (75,800 cells) indicate that the eastern section is the most fertile of the areas studied.

Chaetoceros densus Cleve. This was very rare in net samples, and was not observed in the sedimentation cylinders. It is an oceanic species in the Gulf of Maine, according to Gran and Braarud (1935).

Chaetoceros furcellatus Bailey. This was quite rare in the net hauls, probably because of its small size, but was taken in nets at stations 502 and 540. It occurred at the surface at station 544 as 3,620 cells/l. Larger numbers were found at station 603, where 100,000 cells were recorded at the surface and 6,200 cells at 10 m. At station 612, where it was absent at the surface, it reached a maximum of 48,000 cells at 50 m, at station 617, 14,000 cells at the surface, 10,000 at 10 m. 320,000 at 25 m, 39,000 at 50 m and 9,800 at 90 m. Sinking capacity was increased by the presence of numerous cysts.

This arctic-neritic diatom was the most abundant in Sugluk Fjord and was generally more numerous in the northern part of Hudson Bay than elsewhere in the region. It is possible that large populations which occurred in the deeper waters represented a physiological phase in which the organisms are heavier than sea water, one in which cysts are formed.

Chaetoceros gracilis Schütt. It occurred at stations 502, 520, 540, 549 and 612 in net hauls. It was found as only 160 cells/l at 50 m at station 517. Neritic-arctic, it is rather common in Hudson Strait.

Chaetoceros karianus Grun. This truly arctic species was found in net hauls at only 4 stations. It occurred at station 510 as 1,080 cells/l at the surface, and at station 549 as 6,000 cells at the surface, the latter location indicating movement southward from Foxe Basin. It is a small species which may often escape plankton nets. Found in the Kara and Barents Seas, it was recorded also by the Godthaab Expedition from West Greenland waters.

Chaetoceros laciniosus Schütt. Common at stations 503, 512, 520, 526, 527, 531, 549 and 612, in net hauls. Populations of 4,080 cells/l at the surface and 3,380 at 10 m were observed at station 507. At station 520 a few hundred per litre were found. The maximum at the depth of three m was encountered at station 602, reaching 19,600 cells. The waters at station 603 contained 42,400 cells/l at the surface, and 60,000 at 10 m. This neritic-arctic species shows a wide distribution in Greenland waters, according to Grøntved and Seidenfaden (1938).

Chaetoceros lorenzianus Grun. This species was not previously reported from the area, nor was it found in waters adjacent to Hudson Bay. The cysts and characteristic structure of *Ch. lorenzianus* were examined carefully, and they prove that the identification is correct. It occurred in net tows at eight stations. At station 506 small populations from 920 to 2,000 per litre were counted. At station 507, 16,800 were found at the surface. Smaller populations also were recorded at stations 509, 510, 514, 515, 520, 521, 522, 529 and 535. At station 544, 3,500 cells were observed at the surface. The maximum of 32,200 cells/l occurred at 5 m at station 602, where the diatom was also noticed at various depths down to 15 m. A large population of 38,520 occurred at station 612 at 50 m, an unusual find explained by the presence of cysts, and increased sinking conditions.

Chaetoceros socialis Lauder. Rare in net hauls at stations 553, 602, 603 and 612, it occurred in quantitative collections at station 617 as 300,000 cells/l at the surface, 81,000 cells at 10 m, 10,000 cells at 25 m and 1,500 cells at 50 m. Station 618, though in open waters, contained 194,000 cells at the surface, 59,600 cells at 10 m, 7,200 at 25 m and 8,000 at 50 m. Cysts were often observed. This neritic-brackish species is abundant on the coast of northern Europe. It occurs in brackish lagoons on the north Alaskan coast (author's unpublished data).

Chaetoceros septentrionalis Ostr. (Fig. 2). This species is probably more common in the region than collections indicate, but it is difficult to observe because of its small size. It occurred in horizontal net hauls at stations 502, 555 and 603.

Chaetoceros teres C. This was taken at stations 502, 531, 535, 540, 603 and 612 in net hauls. Cysts were not found. A few hundred cells per litre were recorded at station 507, and 400 cells were found at 50 m at station 535. It appeared also at station 544 in small numbers between 25 and 100 m. The maximum of 1,200 cells/l occurred at station 612 at 25 m. A temperate form, it is rare in the north.

Chaetoceros subsecundus (Grun.) Hustedt. This occurred in small numbers in the net hauls at Hudson Bay stations where cysts were observed. It is neritic on the European coast, in the Arctic Ocean and in the Mediterranean Sea (Grunow, 1884). It was observed at station 520 at 10 m as a population of 5,200 cells/l and at station 521 as a few hundred cells. The maximum of 14,360 cells was at 25 m at station 522. The maximum at the surface was found at station 544, as 10,500 cells/l, while populations of a few thousand were observed in the deeper layers. In the present state of our knowledge of the distribution of warmer-water plankton species it is not possible to classify species exactly as to their temperature requirements. It is not yet possible to distinguish between endemic species and those introduced by currents into the Bay.

Chaetoceros wighami Bright. This was occasionally found in the net hauls at stations 502, 617 and 618. It is a rare organism in Hudson Bay. According to Grøntved (1950) it is a truly arctic species. Braarud (1935) observed it in

Arctic waters east of Iceland and at the border of the Polar Current.   It formed in some localities the main component of the net plankton.
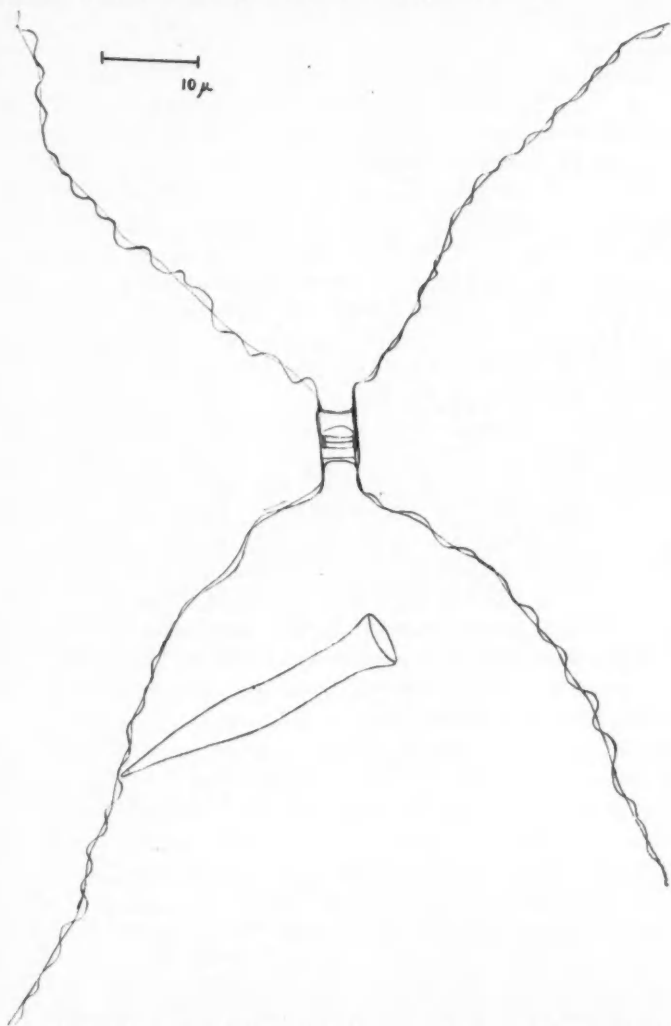
Fig. 2. *Dinobryon utriculus* epiphytic upon *Chaetoceros septentrionalis* (camera lucida).

Coscinodiscus concinnus Sm.   This pelagic diatom is reported here for the first time from Hudson Bay. It was recorded previously from the eastern Canadian arctic and from the Gulf of Maine.   It is common in the North Sea even in winter plankton.   It is probably brought from Atlantic waters.   At

station 508, 920 cells/l were recorded.   At station 520, at 25 and 50 m, 360-440 cells were present.   The maximum at the surface was found at station 544 as 2,000 cells/l.

Coscinodiscus oculis iridis Ehrenb.   Found in oceanic plankton in all seas, it is quite common in Hudson Bay and occurred in net hauls from stations 502, 503, 540, 553 and 602.   It is very common in Greenland, Cleve (1873), and occurs in immense masses in the month of May in Disko Bay, later in the year becoming scarcer (Grøntved and Seidenfaden, 1938).   It is not recorded by Gran and Braarud (1935) from the Gulf of Maine.   Since it usually has been found in large numbers in northern latitudes, its seasonal maximum in our area probably took place earlier than the *Calanus* samples were collected.

Coscinodiscus excentricus Ehrenb.   Regularly observed by Gran and Braarud (1935) in the centrifuge samples from the Bay of Fundy and Gulf of Maine, according to Grøntved (1950) this species is as a rule considered as truly oceanic. In our observations this species occurred occasionally in net hauls but it was not observed in the sedimentation cylinders.

Coscinodiscus marginatus Ehrenb.   This Atlantic species was rare in net hauls and was observed at stations 526, 540, 549 and 612.   It had not been observed formerly in the Hudson Bay area, and was not reported from the Gulf of Maine.   It is possible that it is brought from the Atlantic to Hudson Bay.

Coscinodiscus grani Gough.   A neritic species, it was not reported previously from the eastern arctic or the Gulf of Maine.   Rare in net hauls, it was found at stations 502, 512, 527, 549 and 612.   It is possible that this diatom also is introduced by currents from the Atlantic.   It was observed through the column of water at station 506 and had its maximum of 1,580 cells/l at 50 m.   Though it occurred at many stations, represented by a few hundred cells, it is considered as a relatively unimportant organism.

Coscinodiscus lineatus Ehrenb.   Known from all seas in oceanic and neritic environments, it is recorded from Norway and Denmark (Hustedt, 1930) and from the Faeroe Islands.   Formerly unknown from the Hudson Bay area.

Cyclotella sp.   This is probably a freshwater species, found in inshore plankton at the surface, and represented by a few hundred cells/l.   The largest number of this allochthonous form was 3,000 cells/l.

Eucampia zodiacus Ehrenb.   This large neritic diatom occurred in net hauls at stations 502, 540, 549 and 612.   It was found at 3 stations (521, 535 and 544) discontinuously recorded through various depths in small numbers.   More frequent numerically in Hudson Strait than in Hudson Bay plankton, there were 30,000 cells/l at station 617 and 13,000 at 100 m.   Gran and Braarud (1935) observed it from April to June and rarely in August, but it was never abundant in the Gulf of Maine, where its maximum was 2,000 cells/l.

Fragillaria cylindrus Grun.   This species was previously recorded in some samples of Nilsson from the Baffin Island coast (Cleve, 1896).   Observed in net hauls from 6 stations, its vertical distribution was discontinuous, with a few

thousand cells/l, absent from the surface, at stations 503, 509 and 535. The large number of 86,000 cells/l occurred at station 617, with gradually diminishing numbers at 25, 50 and 100 m.

Fragillaria crotonensis (A. M. Edwards) Kitton. A neritic, brackish species, it was found occasionally in small numbers at 6 stations.

Fragillaria oceanica Cleve. This arctic-neritic species was observed in 2 horizontal net hauls. It is included in Gran and Braarud's (1935) list of species rare in plankton. Grøntved (1950) recorded it in the eastern Canadian arctic.

Fragillaria islandica Grun. This neritic-arctic species is represented in early diatom spring plankton, and therefore is rare in the samples collected later. It appeared at stations 502, 503, 520, 531, 555 and 549. It was not recognized in the quantitative survey. It is abundant in Hudson Strait (Polunin, 1934).

Fragillaria nana Nielsen. A temperate species, it occurred in the net plankton at stations 502, 520, 531, 540 and 553. It was seen at station 517 at the surface as only 440 cells/l and as a larger population at 10 m of 2,470 cells/l.

Leptocylindricus danicus Cleve. This was rare in quantitative samples. A temperate-boreal species, it is scattered in the Canadian eastern arctic (Grøntved, 1950), and very abundant north of Europe. Gran and Braarud (1935) found a maximum of 5,000 cells/l in Passamaquoddy Bay.

Navicula vanhoffeni Gran. Observed at 8 stations, it seems to be distributed over the whole area in small numbers. It is an arctic form.

Navicula sp. A small, neritic form, this occurred at coastal stations in net hauls and sedimentation cylinders as populations of a few hundred cells per litre.

Nitzschia frigida Grün. Recorded on a few occasions in horizontal net hauls, it is a truly arctic neritic form, mostly attached to sand or mud particles.

Melosira arctica Dickie. This species was observed by Ross (1947) as a typical ice diatom, in the ice or attached to the ice, in early spring. Recorded as 5,800 cells/l at the surface at station 529, it occurred in small numbers only at stations 503 and 515.

Melosira islandica Müller. This freshwater species was found mostly in horizontal net hauls, and was dominant at stations 502 and 514, rare at stations 531 and 612. Its maximum was at station 509, as 1,560 and 1,300 cells/l at 25 and 50 m.

Melosira nummuloides (Dillw.) Ag. It occurred only at station 502, in net plankton.

Nitzschia delicatissima Cleve. This widely distributed species, according to Gran and Braarud (1935), may be regarded as oceanic, although it is often abundant in inshore waters. According to Grøntved (1950) it is a temperate species, presumably coming to our area only with northward moving water in the autumn. It was not reported previously from Hudson Bay. This shows a very limited occurrence at stations 506, 514 and 527.

Nitzschia closterium Sm.   This occurs frequently in the plankton, and was recorded over the whole area in eight hauls.   It is more common than other species of the genus and has continuous vertical distribution at 6 stations.   The maximum found was 18,980 cells/l at 25 m at station 544 in Foxe Channel.   A smaller population of this diatom (13,000 cells) occurred at the surface.   It is remarkable that quantitative fluctuations of this diatom in the majority of samples was within a few hundred cells.

Nitzschia seriata Cleve.   This is a common species, often associated with *N. closterium*.   Polunin (1934) found it to be rare in Hudson Strait, Davidson (1931), wide-spread in Hudson Bay, but "in very small numbers".   Grøntved suggested that it is probably most common early in the year.   It is a northern to arctic neritic species, present at Scotch Cap, Alaska (Cupp, 1943), and recorded by Gran (1912) as an arctic, oceanic species.   Populations were small in Hudson Bay, with a maximum of 2,400 cells/l.   It was more common in Hudson Strait stations, its maximum of 10,000 cells occurring at station 617, at 25 m.

Podosira glacialis (Grun.) Jorg.   Found frequently in Hudson Strait in 1953, it is reported here for the first time from Hudson Bay.   Gran and Braarud (1935) consider it as a typical spring form.   It was observed at stations 502, 520 and 553 in net hauls; otherwise 200 cells/l occurred at station 612 at 10 m.

Rhizosolenia styliformis Brugh.   It is rare in Hudson Strait, Polunin (1934) and Davidson (1931) reporting it from Hudson Bay.   It occurred over the whole area in net hauls and in very scattered populations of a few hundred cells/l at 12 stations.

Rhizosolenia hebetata f. *hiemalis* Gran.   This occurred only in the net hauls as a very rare form.   A true "autumn type" in the eastern Canadian arctic (Grøntved), it was never abundant in the Gulf of Maine (Gran and Braarud, 1935).

Rhizosolenia hebetata f. *semispina* (Hensen) Gran.   An Atlantic species, it was found only in the net plankton at stations 502, 503, 520 and 540 and is regarded as a late autumn species.

Rhizosolenia imbricata var. schrubsolei.   This oceanic species was found in horizontal plankton samples, at stations 512, 514, 520 and 528, in small quantities.

Rhizosolenia fragillissima Bergon.   This neritic species was found in the net plankton only at stations 502 and 531.   Not reported formerly from Hudson Bay, it is known from the Gulf of Maine.

Sceletonema costatum (Greville) Cleve.   This neritic-boreal species was found only in net hauls at stations 520, 531, 535 and 549, and was not seen in the sedimentation cylinders.   It probably belongs to the Atlantic-neritic group which, although they may occur in Hudson Bay, appear not to propagate satisfactorily there and so do not become important in the phytoplankton.   The species was common in the October plankton of the Godthaab Expedition.   In the Gulf of Maine its maximum is in the warmest season (Gran and Braarud, 1935).

Stephanodiscus astrea (E.) Grun.   This freshwater species occurred mostly in net samples, being observed in small numbers at stations 502, 520, 521 and 540. It has not been reported before from Hudson Bay.

Surirella sp.   Present at stations 502, 520 and 551, it is a benthic freshwater diatom, observed only as single cells.

Thalassionema nitzschioides Grun.   This eurythermic and cosmopolitan species (Smayda, 1958) was observed in six horizontal net hauls.   It was not abundant.   Maximum numbers occurred at station 612, where 8,360 cells/l were found at the surface, and also at 25 m.   Gran and Braarud (1935) found it dispersed over the whole area of the Gulf of Maine from April to September with numbers up to 100,000/l.

Thalassiothrix longissima Cleve and Grun.   This large, oceanic species, considered also as an arctic-boreal or north temperate species, was rare in the net hauls as far as the number of individuals was concerned, but it had a wide distribution at stations 514, 520, 531, 535, 549, 551, 553 and 612.

Coscinosira polychorda Gran.   A neritic north temperate species, it is widely distributed in the arctic (Cupp, 1937, 1943).   It was occasionally found in small quantities in the net plankton.   Its maximum, at 10 m, reached 3,600 cells at station 603, and 2,620 at 50 m at station 544.

Thalassiosira decipiens Grun.   Joerg.   This neritic, north temperate species was rare in the net hauls, taken at only a few stations.   In European waters it has a similar distribution; as in the Gulf of Maine it is very common, but never abundant.   It usually is relatively prominent in the plankton in winter and probably has a slow rate of propagation and relatively low light requirements (Gran and Braarud, 1935).

Thalassiosira subtilis (Ostenf.) Gran.   This was observed by Polunin (1934) in the Hudson Strait area and was considered as a common species.   It was found in the net plankton samples, where it occurred at 8 stations.   At station 517 a population of 4,800 cells/l was found.

Thalassiosira gravida Cleve.   This species occurred in small and discontinuous populations, which are significant in the total phytoplankton production in Hudson Bay.   Its maxima of 98,000 cells/l at the surface and 102,000 at 25 m were found at Sugluk (station 617) in Hudson Strait.   Smaller populations of this organism occurred within the neritic area of Evans Strait, close to Coats Island, continuously distributed vertically.   It was considered by Gran (1912) as an arctic neritic form.

Thalassiosira rotula Meunier.   This species appeared at all stations.   It is considered as a significant producer of biomass and food, because of its large size. Continuous vertical occurrence was observed at stations 509, 510, 516, 517 and 549 in varying numbers from a few thousand to over 20,000 cells/l.   The maximum at the entrance to Hudson Bay occurred at 25 m at station 602 where it reached 210,600 cells/l.   The numerical increase of this diatom towards Hudson Strait

is well marked by its continuous vertical distribution. The maximum in Hudson Strait was found at station 617 at the surface, represented by 220,000 cells/l. It was considered by Polunin (1934) as a temperate visitor in autumn. Grøntved and Seidenfaden (1938) called its appearance in Hudson Strait "peculiar" since it was regarded as a southern temperate form.

Occurrence of fairly large populations of *Th. rotula* in the northernmost part of Foxe Basin (unpublished data) indicate that it is a form well adapted to severe arctic conditions and that it is probably indigenous to those waters. Whether such populations originated from the Atlantic stock cannot be established yet. It was not however recorded in the Gulf of Maine by Gran and Braarud. The distributional pattern of *Th. rotula* is not established yet in the arctic waters. Cupp (1937) defines it as a neritic, temperate and south temperate species, moderately common off southern California. Present in the Gulf of California and north to Scotch Cap, Alaska, *Th. rotula* was found also in phytoplankton of the coastal waters of Point Barrow (unpublished data), but in net plankton only. Populations in arctic waters are supposedly introduced from the Pacific and Atlantic by currents. Factors controlling the discontinuous distribution of this diatom are still obscure.

The benthic diatoms were fairly common in the net and reverse microscope samples. They are not adapted to the floating life in plankton owing to their heavy membranes and secreted mucus serving for attachment to solid substrate. They are introduced to plankton in turbulent or stormy waters. The more common forms were *Gyrosigma spenceri*, *Gyrosigma* sp., *Grammatophora marina*, *Isthmia nervosa*, *Licmophora abbreviata*, *Melosira nummuloides*, *M. arenaria*, *Navicula* sp., *Pleurosigma* sp., *Pinnularia* sp., *Rhabdonema arcuatum*, *Cocconeis placentula*, *Cymbella* sp., and *Surirella* sp.

QUANTITATIVE DISTRIBUTION AND ECOLOGY OF THE DINOFLAGELLATE SPECIES

These forms have received little attention in northern waters. Calkins (1901) reported them from Nova Scotia, and Gran (1919) recorded more common forms from the Gulf of St. Lawrence. Martin (1929) found some new species in non-arctic marine and brackish habitats. Gran and Braarud (1935) contributed to our knowledge of the Gulf of Maine. Seidenfaden (1947) made a list of dino-flagellates from the Canadian arctic. The distribution of *Ceratium* sp. in the Newfoundland area was studied by Frost (1938). Many new species were described by Gaarder (1954) from the Atlantic area. Holmes (1956) studied the quantitative dynamics of dinoflagellates in the Labrador Sea. Experiments by Barker (1935), Braarud (1945) and others show the dinoflagellates are a warm water group. The absence of many thecate species in the arctic allows us to conclude that low temperature and dim arctic light do not favour them.

Sixty-two species were found in the Hudson Bay and Hudson Strait material. In a special survey of dinoflagellates, 41 more species were found in Hudson Bay and Hudson Strait (unpublished data). The so-called "naked" dinoflagellates

which are deformed or burst after fixation cannot be identified properly in preserved material.

Genus *Ceratium*. The most common species in the *Calanus* samples were *C. arcticum* and *C. longipes*. *C. tripos* was less common and *C. hirundinella* occurred only once in a net haul, indicating freshwater influence from the Churchill River. *C. macroceros* and *C. bucephalum* were found mostly in the Hudson Strait area. The rare *C. karsteni*, from station 618, seems to be an Atlantic species. It is remarkable that *C. fusus*, *C. lineatum* and *C. furca*, common in the Atlantic and at Point Barrow, Alaska, were entirely absent from the *Calanus* collections. All *Ceratium* species were represented by small populations, except at station 505, where 1,040/l were counted from 10 m. Frost (1938) considered *Ceratium* species as indicators of hydrographic conditions in Newfoundland waters. No similar use could be made of the material treated here because of the infrequent occurrence of the species.

Goniaulax tamarensis, studied by Braarud (1945) and Gaarder (1954), was common at many stations, where numbers ranged from a few hundred to 11,000 cells/l (the latter at station 544). The species was found ingested by *Ptychocylis*, *Parafavella*, *Tintinnopsis* and other ciliates. Foecal pellets containing *G. tamarensis* indicate that some unidentified crustaceans can feed selectively on *Goniaulax*, and suggest that such grazers are able to reduce considerably populations of the genus. Paralytic shellfish poisoning has been associated with *G. tamarensis* in certain parts of the Bay of Fundy where it constitutes the food of molluscs (Needler, 1949).

COCCOLITHOPHORIDINEAE, SILICOFLAGELLATAE, CHRYSOMONADINEAE, BODONIDEAE AND MINOR GROUPS OF FLAGELLATES

Although the taxonomic identification of Coccolithophoridineae cannot be done suitably with the light microscope, an effort was made to identify some of the organisms and to count them. *Coccolithus huxleyi* was fairly common in Hudson Bay, populations occurring mostly at the surface and at 10 m, probably because of higher temperatures in the upper water layers. Numbers at station 507 were outstanding, reaching 1,438,000 cells at the surface and 480,000 cells/l at 10 m. At station 506, 631,000 at the surface and 63,000 cells/l at 10 m were found. Smaller numbers were found in Hudson Strait.

Distephanus speculum (Ehrenb.) Heckel. This organism, abundant in warm seas, including European waters (Gran, 1915), was very rare in this material. Another silicoflagellate, *Ebria tripartita* (Schum.) Lemmermann, also common in boreal waters, occurred only twice in the net hauls.

Bodo sp. A small holozoic form with two uneven flagella occurred at station 503, represented by a population of 3,500 cells/l. The greatest number was found at station 549, as 29,000 cells/l. This organism is not identical to the species of *Bodo* found by Braarud and Bursa (1939) in Oslo Fjord.

Dinobryon balticum (Schütt) Lemmermann.   Common in fresh and brackish waters of Europe, this species was found at Point Barrow, Alaska, in larger numbers and at different depths than in Hudson Bay (author's unpublished data). *D. balticum* and *D. pellucidum* can adapt themselves to euryhaline habitats during the melting period of arctic ice and then become mixed with the brackish surface and deeper water of high salinity.   The intrusion of freshwater microflora into the marine environment is associated with river influence and ponds of melting ice found abundantly in summer over the arctic area.   The contrast in occurrence of *Dinobryon* in Hudson Bay (station 507) and Hudson Strait (stations 600, 612, 617 and 618) is shown in Table II.

TABLE II. *Dinobryon* occurrence in Hudson Bay (station 507) and in Hudson Strait (stations 600, 612, 617 and 618).

Depth	Station				
	507	600	612	617	618
m.					
0	9,000	30,000	17,000	11,000	38,400
10	–	3,900	34,000	8,000	31,200
25	–	40,200	3,500	17,600	2,500
50	–	–	–	1,200	–

Dinobryon pellucidum Levander.   This was less common than *D. balticum.* It is fairly common in Greenland waters, according to Grøntved and Seidenfaden (1938).

Dinobryon utriculus Stein.   This is another rare freshwater organism which has not been reported formerly from brackish or marine waters.   Only a few specimens were seen in a net sample from station 529.   One of them was attached to the diatom *Chaetoceros septentrionalis* (Fig. 2), such an epiphytic phase indicating that the small population was introduced into the sea from fresh water.

REMARKS ON TAXONOMY OF SOME RARE AND UNKNOWN SPECIES

Pterosperma reticulatum Ostenf.   (Fig. 3).   Spherical cells with a hexagonal membrane reticulum. Protoplasm dense, containing yellow pigment indicating that *Pterosperma* is of phytogenous origin and related to the Heterocontae. Specimens from Canadian waters are identical to those from the Red Sea (Ostenfeld and Schmidt, 1901, after Gaarder, 1954). Specimens from Florida were 80 to 100 μ and had fewer polygons, from north of Spain and east of Newfoundland 30 to 77 μ (Gaarder, 1954).
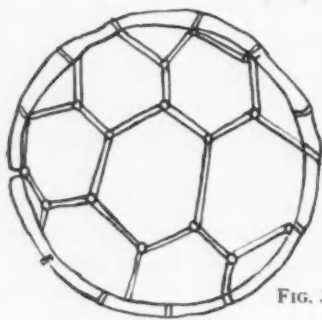
FIG. 3. *Pterosperma reticulatum* (*camera lucida*, × 2400).

Pterosperma ovum Gaarder. This form was described by Gaarder (1954) from south of Ireland, and several specimens were also collected off Cape Finisterre (Spain). As far as general morphological features are concerned, specimens here are almost identical to the descriptions and drawings of Gaarder (1954, fig. 19a, b), except for size, the Hudson Bay cells being larger. The cell diameter of Gaarder's specimens was 28 to 46 μ, including lamellae 55 to 62 μ; in the Hudson Bay material length, including lamellae, is 230 μ, breadth 100 μ, length of the cell, without lamellae, 125 μ. The large size of the Hudson Bay specimens therefore puts them closer to Lohmann's *P. ovum hispidum gigas* (1904, p. 31, pl. V, fig. 7) from the Florida Current (after Gaarder, 1954). Lohmann's specimens, with a diameter of 390 μ, have branching protuberances separated at the base, shorter than in the Hudson Bay form. Gaarder supposed that *P. ovum hispidum gigas* might be identical to Stein's "cysts of *Cladopyxis brachiolata*" (1883, p. 19, pl. II, fig. 12, 13) from Helgoland, and others found in salps in the South Seas, specimens in which the branching protuberances may have a continuous film at the base. The Hudson Bay form is closely related to the fossil *Hystrichosphera* spp., especially *H. ramosa* (Ehrenberg) and *H. wetzel* (Deflandre, 1952, p. 324, fig. 17).

Rhabdosphera spinosa Gaarder. Spheroid and subspheroid cells were found at station 603. They are similar to but smaller than previously described specimens. Some contained brown or green pigment, indicating the holophytic origin of the organism. The numerous spines were of uneven size, about 2 to 4.5 μ in length. The cell membrane was bi-contoured and thick. Length of the subspheroid cells was from 18 to 20 μ, breadth from 11 to 13 μ, while Gaarder's (1954) specimens were from 30 to 45 μ. Elsewhere the species is known along the northwest African coast and in the area between the Azores and the Sargasso Sea.

UNIDENTIFIED EPIPHYTIC CHRYSOMONADINEAE

A small, probably holozoic epiphytic chrysomonad, with protoplasm enclosed within the tubular membrane, open at the top, wider than the base, is shown in Fig. 4. The shrunken protoplasm contains a nucleus and some products of

Fig. 4. Lorica of an unidentified chrysomonad (*camera lucida*, × 2400).

10 μ
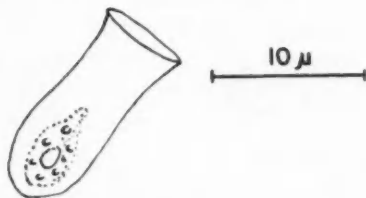
metabolism. It was attached to the bottom of the tube-shaped membrane. Some free and floating individuals were found, attached to a diatom, at station 503. It is possible that these organisms came from a river, together with the

diatoms upon which they grew.   Dimensions are: length of the membrane, 15 μ; breadth of the apex, 6 μ; breadth of the attachment, 4.5 μ.

Polyasterias problematica (Cleve) Meunier.   This enigmatic organism (Fig. 5), recorded from the middle Baltic by Rumek (1948) and others, was studied more recently by Erdtmann (1954) and Gaarder (1954).   *Polyasterias* was found commonly in horizontal plankton hauls at stations 553 and 603.   Most specimens possessed 6 hyaline arms, symmetrically disposed, with broadened and serrated ends around the spherical cell in the centre.   There were also 7-, 8- and even
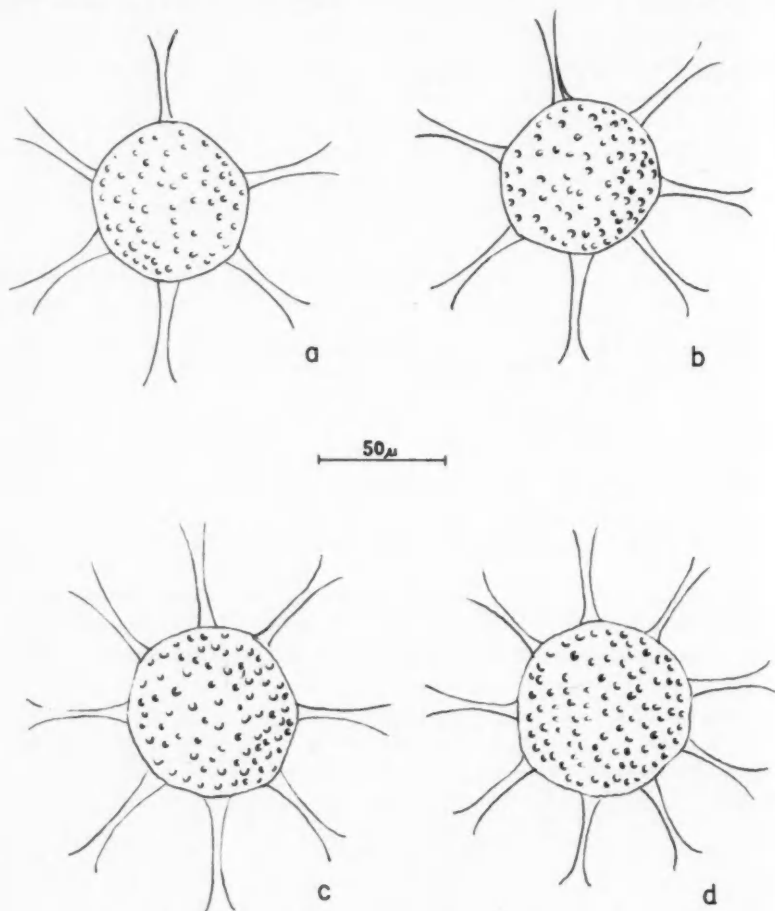
Fig. 5.   *Polyasterias problematica (camera lucida).   a,* 6-armed; *b,* 7-armed; *c,* 8-armed; and *d,* 9-armed forms.

9-armed specimens, all quite rare. Gaarder (1954) found specimens with 5 protuberances, and one with 6, off Cape Finisterre (Spain) and south of the Azores.

The author's observations in the Baltic (unpublished data), carried out on live *Polyasterias*, showed that small and larger colourless swarmers are formed inside small cells, liberated probably through the openings found within the arms. Since the organism is rare, the origin of the individuals with varying numbers of protuberances is unsolved. Dimensions of the Hudson Bay specimens: length of the arms, 32 to 40 μ; diameter of central cell and arms, 150 μ. Occurrence elsewhere is the Baltic, Atlantic, North Sea, Skagerrak.

Unknown flagellate cysts (Fig. 6a, b). These were observed at stations 603, 528 and 502. Figure 6a shows a cyst with well defined pores. The membrane was sculptured with delicate dots in regular order. Small spines were observed
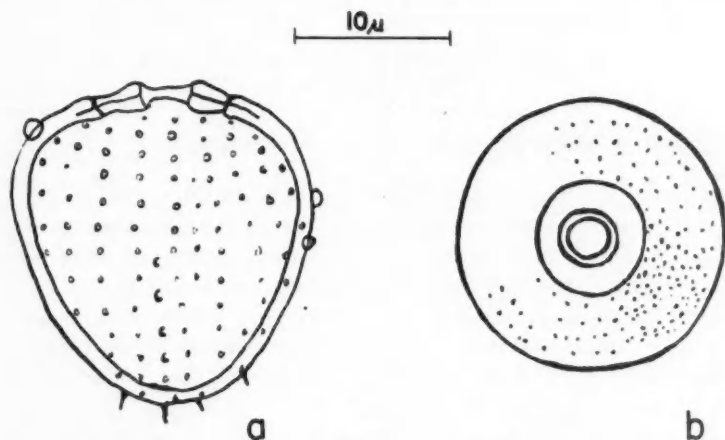
FIG. 6. Cyst of an unidentified flagellate (*camera lucida*, $\times$ 2400). *a*, side view; *b*, front view, showing the apical pore.

on the posterior part of the cyst. The membrane was bright yellow. The colourless protoplasm with reserve materials and nucleus indicates the holozoic nature of the cyst-forming organism. The cyst in apical view (Fig. 6b) shows a round pore opening surrounded by a wide outside and narrow inside ring. Length was 28 μ, breadth 12 μ. The specimen figured was taken at station 528 on August 9, 1953.

Other cysts of unidentified flagellates were observed at station 549 in small numbers in horizontal net hauls in September 1953. Figure 7a-c shows cysts with large wrinkled membrane collars, with the irregular folds of the collar

membrane running excentrically. The spherical cell had a yellow-brown membrane in which small and large grains of reserve materials were observed. The surrounding hyaline membrane varied from 6 to 14 μ.
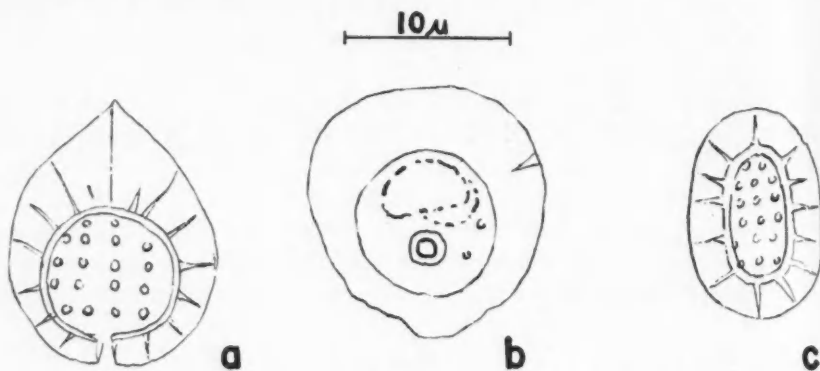
FIG. 7. Cyst of an unidentified flagellate (*camera lucida*, $\times$ 2400). *a*, lateral view; *b*, front view, showing apical pore; *c*, side view.

OCCURRENCE OF SPECIES IN THE VERTICAL AND HORIZONTAL NET HAULS

While even the finest plankton nets cannot be used for accurate estimation of phytoplankton biomass, because of loss of the smallest organisms through the net meshes, net tows may be extremely useful in supplementing the relatively small quantitative collections to give increased qualitative results. A fairly short net tow will sample many hundreds of times the water volume of one quantitative collection taken from a closing bottle (and examined with the inverted microscope), and thus increase greatly the chance of collecting the rarer organisms. As an example of this, station 502 (5 miles northwest of Churchill) yielded 33 species according to the inverted microscope examination, and 39 additional species in the net tow. In this group 16 marine diatoms and 8 dinoflagellates were autochthonous, while 12 species, like *Asterionella gracillima*, *Gomphonema* sp., Cyanophyceae, Desmidiaceae and green algae showed a freshwater origin.

Coexistence of Atlantic, arctic and freshwater forms was noticed on a few occasions in the *Calanus* samples of 1953 and 1954. This feature was most apparent in the clearly mixed waters of Hudson Strait. The number of species in autochthonous populations in strictly arctic water appears to be smaller than in areas where various water types are mixed (e.g. arctic and Atlantic). This is shown clearly by the genus *Ceratium*. In the mixed waters of northern Hudson Bay 7 species of *Ceratium* were found, while in the arctic waters of Foxe Basin (author's unpublished data) 2 species were recorded, *C. arcticum* and *C. elongatum*, the only true arctic forms of the genus.

TABLE III. Diatoms found in Hudson Bay and Hudson Strait.

Achnantes taeniata Grunow
Amphiprora hyperborea Gran
Asterionella kariana Grunow
A. gracillima Heib.
Asterolampra sp.
Attheya decora West
Bacteriosira fragilis Gran
Biddulphia aurita Brebisson & Goday
Chaetoceros atlanticus Cleve
Ch. borealis Bailey
Ch. concavicornis Gran
Ch. convolutus Castracane
Ch. compressus Lauder
Ch. constrictus Gran
Ch. curvisetus Cleve
Ch. decipiens Cleve
Ch. debilis Cleve
Ch. eibeni Grunow
Ch. furcellatus Bailey
Ch. diadema Ehrenberg
Ch. gracilis Schütt
Ch. lorenzianus Grunow
Ch. laciniosus Schütt
Ch. teres Cleve
Ch. septentrionalis Oestrup
Ch. socialis Lauder
Ch. karianus Grunow
Ch. wighami Brightwell
Chaetoceros sp.
Cocconeis placentula Ehrenberg
Coscinosira polychorda Gran
Coscinodiscus concinnus Smith
C. oculis iridis Ehrenberg
C. grani Gough
C. marginatus Ehrenberg
C. lineatus Ehrenberg
Coscinodiscus sp.
Stephanodiscus astrea Grun.
Eucampia zodiacus Ehrenberg
Fragillaria cylindricus Grunow
Fr. striatula Lyngb.
Fr. crotonensis Kitton
Fr. nana Nielsen
Fr. oceanica Cleve

Fr. islandica Grunow
Gyrosigma spenceri Cleve
Grammatophora marina Cleve
Isthmia nervosa Kützing
Leptocylindricus danicus Cleve
L. minimum Gran
Licmophora abbreviata Agardh
Melosira arenaria Moore
M. arctica Dickie
M. islandica Karsten
M. nummuloides Agardh
Melosira sp.
Navicula distans Smith
N. vanhoffeni Gran
Navicula sp.
Nitzschia closterium Smith
N. delicatissima Cleve
N. pungeus Gran
N. seriata Cleve
N. frigida Grunow
Porosira glacialis Jörgensen
Pleurosigma sp.
Pinnilaria sp.
Rhabdonema arcuatum Kützing
Rhizosolenia alata Brightwell
Rh. styliformis Brightwell
Rh. styliformis v. shrubsolei Gran
Rh. styliformis v. hebetata Gran
Rh. fragillisima Bergon
Sceletonema costatum Cleve
Stephanopyxis nipponica Gran & Yendo
Surirella sp.
Actinoptychus undulatus Ralfs
Thalassiosira bioculata Ostenfeld
Th. gravida Cleve
Th. hyalina Gran
Th. nordenskjöldi Gran
Th. rotula Meunier
Th. subtilis Gran
Th. decipiens Jörgensen
Thalassiosira sp.
Thalassionema nitzschioides Grun
Thalassiothrix frauenfeldti Grunow
Th. longissima Cleve & Grunow

TABLE IV. Dinoflagellates found in Hudson Bay and Hudson Strait.

Amphidinium sp.	*P. conicum* Ostenfeld
Glenodinium lenticula Schiller	*P. crassipes* Kofoid
Glenodinium sp.	*P. curvipes* Ostenfeld
Goniodoma polyedricum Jörgensen	*P. denticulatum* Gran & Braarud
Goniaulax catenata Kofoid	*P. depressum* Bailey
G. spinifera Claparède & Lachmann	*P. divergens* Ehrenberg
Goniaulax sp.	*P. obtusum* Karsten
Exuviella baltica Lohmann	*P. leonis* Pavillard
Ceratium arcticum Cleve	*P. pallidum* Ostenfeld
C. bucephalum Cleve	*P. pentagonum* Gran
C. longipes Gran	*P. curvipes* Ostenfeld
C. macroceros Cleve	*P. subcurvipes* Lebour
C. tripos (Mueller) Nitzsch.	*P. oceanicum* Vanhoffen
C. lineatum Cleve	*P. trochoideum* Lemmermann
C. karsteni Jörgensen	*P. thorianum* Paulsen
Ceratium sp.	*P. triquetrum* Lebour
Dinophysis acuminata Claparède & Lachmann	*P. grani* Ostenfeld
D. acuta Ehrenberg	*P. brevipes* Paulsen
D. grani Paulsen	*P. islandicum* Paulsen
D. islandica Paulsen	*P. roseum* Paulsen
D. arctica Broch	*P. finlandicum* Paulsen
D. norwegica Claparède & Lachmann	*P. steini* Jörgensen
D. robusta Braarud (cysts)	*P. subinerme* Paulsen
Oxytoxum gladiolus Stein	*P. mite* Pavillard
Peridinium avellana Leb.	*P. globulus* Stein
P. minusculum Pavillard	*Prorocentium reticulatum* Bütschli
P. achromaticum Levander	*Phalacroma rotundatum* Clap. & Lachm.
P. cerasus Peters & Smith	*Ph. rudi* Braarud

TABLE V. Flagellates, algae, desmidiaceans and cyanophyceans found in Hudson Bay and Hudson Strait.

Dinobryon pellucidum Levander	*Trochiscia* sp.
D. balticum (Schütt) Lemmermann	*Scenedesmus quadricauda* Brebisson
Coccolithus huxleyi Kamptner	*Peridinium ovatum* Schütt
Coccolithus sp.	*P. simplex* Lemmermann
Distephanus speculum Haeckel	*Aphanizomenon flos-aquae* Ralfs
Ebria tripartita Lemmermann	*Gomphonema* sp.
Bodo sp.	*Anabaena* sp.

TABLE VI. Ciliates found in Hudson Bay and Hudson Strait.

Laboea acuminata Leegaard	*Tintinnus acuminatus* Jörgensen
L. reticulata Leegaard	*T. norvegicus* Dady
L. strobila Lohmann	*Leprotintinnus bottnicus* Jörgensen
L. spiralis Leegaard	*Tintinnopsis beroidea* Jörgensen
L. conica Lohmann	*T. parvula* Jörgensen
Didinium gargantua	*T. karajakensis* Brand
Ptychocylis urnula Brandt	*Tintinnopsis* sp.
P. obtusa (Brandt) K. & C.	*Codonella* sp.
P. arctica (Brandt) K. & C.	*Stenosomella ventricosa* Jörgensen
P. media (Brandt) K. & C.	*Undella* sp.
P. gigantea Kofoid & Cleve	*Woodania conicoides* Leegaard
Ptychocylis sp.	

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The Quality of Fish Flour, Liver Meal, and Visceral Meal as Sources of Dietary Protein[1,2]

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ABSTRACT

Rats were used to test the digestibility and protein quality of dried preparations of muscle and viscera from cod and haddock, and of liver from cod.

The digestibility of the preparations from muscle and viscera was good, and better than that of the preparation from liver.

The metabolic utilization of nitrogen and the support of growth were good in the case of the muscle preparation, and poor in the case of the visceral and liver preparations.

INTRODUCTION

PREPARATIONS OF FISH MUSCLE have been used in feeding experiments with rats, in some cases to supply all of the dietary protein (Drummond, 1918; Kik and McCollum, 1928; Lanham and Lemon, 1938; Nilson *et al.*, 1947; Beveridge, 1947; Morrison and Campbell, 1960), and in others to supplement cereal protein (Kik and McCollum, 1928; Sure, 1957; Morrison and Campbell, 1960). Observations on the growth and studies of the nitrogen metabolism have in all cases produced evidence that these proteins are among the best in nutritional quality.

At the Fisheries Research Board of Canada Technological Station in Halifax, a dry, fat-free preparation of fish muscle has been made, which is called fish flour (Guttmann and Vandenheuvel, 1957). It is 15.0 to 15.7% nitrogen on a dry, fat-free basis, but there is 2 to 3% residual moisture and 2 to 5% ash. The sample which we tested was 14.4% nitrogen, which corresponds to 90% crude protein. Its amino acid composition is known (Guttmann and Vandenheuvel, 1957), and it has been shown to be of high nutritional quality (Morrison and Campbell, 1960). It has been made from cod and haddock filleting trimmings, a cheap source material that can be regarded as an industrial by-product.

Two other preparations also made on a pilot-plant scale at the Station in Halifax from by-products of commercial cod and haddock processing were a visceral meal and a liver meal.

The visceral meal (Freeman and Hoogland, 1956) was prepared from the gastro-intestinal tracts of the fish. The sample which we tested had been drum

dried to a moisture content of 7%. It contained 4% fat. The nitrogen content was 10.9%, 88% of which was non-protein nitrogen.

The liver meal (Power and Vandenheuvel, 1950; Guttmann, 1950) was made by drying the residue from the extraction of cod liver oil. The sample which we tested had been dried to 8% moisture, and contained 12% residual fat. The nitrogen content was 8.7%, almost half of which was present in free amino acids. There was an apparent carbohydrate content of about 10%.

There is interest in the possibility of using the visceral and liver meals as animal food. In relation to this application the most important basic information to be obtained concerns the nutritional value as proteins of their nitrogenous constituents. We did the appropriate tests for this, and also used the same tests for another study of the quality of the protein of fish flour.

The amino acid composition of the visceral and liver meals has not been determined.

The nutritional quality of a protein can be deduced from its amino acid composition if it is known that the digestion of the protein and absorption of the products are complete or nearly so. Otherwise, and always for confirmatory purposes, biological tests are necessary to establish it. There are two widely used methods for obtaining expressions of the nutritional quality. Both involve the feeding of the protein in a balanced diet, for which rats are commonly used. One acquires information on increase in body weight in relation to the intake of protein, the appropriate expression of which is called the *protein efficiency ratio*. The other provides data which allow comparison of the amounts of the ingested and the excreted nitrogen, the difference between which amounts is termed the *nitrogen balance*. The amount of the absorbed nitrogen which is retained can be calculated if the nitrogen in faeces and urine is determined separately, which also allows an estimation of the degree of digestibility of the protein. An expression of the proportion of the absorbed nitrogen which is retained is called the *biological value* of the protein. It differs from the *protein efficiency ratio* by transcending the factor of digestibility. Our experiments provided data for expressing both *protein efficiency ratio* and *biological value*.

The amount of nitrogen in the urine increases with decreasing quality of the dietary protein, but the output of creatinine ordinarily remains constant. Therefore the creatinine portion of the urinary nitrogen varies directly with the quality of the protein. Murlin *et al.* (1953) established this relationship, and pointed out its usefulness in assessing the biological quality of proteins. With this purpose we also determined the urinary creatinine.

PROCEDURE

Some of the diets contained about 11, and some 9 to 10% nitrogenous material calculated as protein (N × 6.25). The first were used to test the fish flour, and the others to test the visceral and liver meals. The difference was necessary because of the lower nitrogen content of the two meals. Egg albumin and casein were used as reference proteins in both cases. In both series the diets

containing the most concentrated protein sources were diluted with cellulose to assist in making those in each series essentially the same in nitrogen content and caloric value. Table I shows the composition of the diets.

TABLE I. The composition of diets.

Group:	I	II	III	IV	V	VI	VII
Source of nitrogen:	Fish flour	Egg albumin	Casein	Liver meal	Egg albumin	Visceral meal	Casein
	%	%	%	%	%	%	%
Nitrogenous constituent	11	12	12	18	10	15	10
Corn oil	10	10	10	10	10	10	10
Salt mixture[a]	4	4	4	4	4	4	4
Sucrose	73.8	73.8	74.4	71.9	71.6	71.8	71.8
Cellulose	1.1	0	0	0	2.2	0	2.6
Sum	99.9	99.8	100.4	103.9	97.8	100.8	98.4
Nitrogen	1.69	1.70	1.69	1.55	1.54	1.39	1.47
Crude protein (N × 6.25)	11	11	11	10	10	9	9

Supplements added per kilogram:

Cod liver oil concentrate[b]	2 mg (400 i.u. vitamin A and 100 i.u. vitamin D)		
α-Tocopherol acetate	30 mg	Pyridoxin hydrochloride	2 mg
2-Methyl naphthoquinone	1 mg	Calcium pantothenate	15 mg
Choline chloride	1 g	Nicotinic acid	2 mg
Inositol	200 mg	p-Aminobenzoic acid	1 mg
Thiamine hydrochloride	2 mg	Biotin	0.3 mg
Riboflavin	3 mg	Folic acid	0.3 mg

[a]Wesson's (1932) modification of the Osborne and Mendel salt mixture, purchased as Salt Mixture W from Nutritional Biochemicals Corp., Cleveland, Ohio.

[b]Ayerst, McKenna & Harrison, Ltd. (Montreal) Special Formula No. 33101, containing 200,000 i.u. of vitamin A and 50,000 i.u. of vitamin D per gram.

Each group consisted of 10 rats, 5 of each sex. The average body weight of those used to test the fish flour (Groups I–III) was 75 g, and of the others (Groups IV–VII) 72 g.

The individual consumption of food was 8 to 12 g per day. An accurate record was kept of the amount consumed by each rat throughout the experimental period, which lasted for 14 days. Water was allowed *ad libitum*. The animals were weighed twice a week.

The rats were accommodated individually in cages with wire-mesh bottoms. On the 14th day they were kept in metabolism cages, and the faeces and urine for 24 hours were collected.

From data on the growth, food consumption, and the excretion of nitrogen, various measures of the utilization of nitrogen, including those indicating the nutritional value of the proteins and nitrogenous material, were calculated.

Nitrogen was determined in food, urine, and faeces by a titrimetric micro-Kjeldahl procedure (Hiller *et al.*, 1948; Sobel *et al.*, 1944), and creatinine by the method of Clark and Thompson (1949).

TABLE II. The utilization of nitrogen by rats.

Ranges, averages, and standard deviations. $N = 10$

Group and source of nitrogen	Entire period, 14 days				Last day							
	Av. weight gain per day	Total weight gain	Total N ingested	Grams weight gain per gram N ingested	Intake of N	N in faeces	N in urine	Creatinine N in urine	Urinary N in creatinine	N* balance	Proportion of ingested N absorbed	Proportion of absorbed N retained
	grams	grams	grams		milligrams	milligrams	milligrams	milligrams	%	milligrams	%	%
I Fish flour	3.6 – 4.4 4.0 ± 0.25	51 – 61 56 ± 3.5	2.56 – 2.77 2.71 ± 0.06	18.4 – 22.3 20.5 ± 1.1	229 – 254 248 ± 9.9	14 – 27 21 ± 4.0	51 – 117 73 ± 18.9	1.3 – 1.9 1.6 ± 0.30	1.5 – 2.8 2.2 ± 0.4	143 – 166 153 ± 14.1	89 – 94 92 ± 1.8	50 – 75 68 ± 7.3
II Egg albumin	3.0 – 4.5 3.8 ± 0.54	42 – 63 53 ± 7.5	2.41 – 2.77 2.65 ± 0.11	16.4 – 23.1 20.1 ± 3.0	219 – 255 248 ± 13.3	10 – 27 20 ± 5.4	37 – 74 56 ± 10.4	1.4 – 2.2 1.7 ± 0.19	2.4 – 3.9 3.1 ± 0.5	147 – 185 172 ± 12.0	89 – 95 92 ± 2.1	67 – 82 75 ± 4.5
III Casein	2.4 – 3.6 3.1 ± 0.41	34 – 51 43 ± 5.7	2.44 – 2.73 2.59 ± 0.09	13.6 – 19.1 16.6 ± 2.0	185 – 256 244 ± 21.6	10 – 24 18 ± 5.0	71 – 106 86 ± 10.9	1.1 – 1.7 1.3 ± 0.17	1.3 – 1.6 1.5 ± 0.1	83 – 159 140 ± 21.8	90 – 96 93 ± 2.1	51 – 66 62 ± 5.3
IV Liver meal	0.4 – 1.1 0.8 ± 0.19	6 – 16 11 ± 2.6	1.78 – 2.09 1.96 ± 0.11	3.4 – 7.8 5.6 ± 1.2	109 – 176 150 ± 24.5	17 – 31 25 ± 5.9	42 – 63 52 ± 6.6	1.0 – 1.8 1.4 ± 0.25	2.3 – 3.5 2.7 ± 0.5	34 – 103 74 ± 21.9	74 – 88 83 ± 4.5	42 – 67 58 ± 8.0
V Egg albumin	3.0 – 3.9 3.4 ± 0.31	42 – 55 48 ± 4.4	2.29 – 2.73 2.55 ± 0.12	16.1 – 24.0 18.8 ± 2.2	176 – 231 220 ± 20.7	7 – 33 18 ± 7.3	41 – 79 56 ± 8.6	1.1 – 1.9 1.6 ± 0.26	2.2 – 3.7 2.9 ± 0.5	112 – 164 146 ± 15.7	86 – 96 92 ± 2.8	63 – 77 72 ± 4.5
VI Visceral meal	(−0.3) – 0.7 0.2 ± 0.36	(−4) – 10 3 ± 5.1	1.44 – 1.81 1.57 ± 0.11	0 – 6.4 2.3 ± 2.9	99 – 177 138 ± 28.9	7 – 15 12 ± 2.8	38 – 63 47 ± 9.4	1.0 – 1.6 1.3 ± 0.18	2.0 – 3.4 2.8 ± 0.5	51 – 106 79 ± 19.9	86 – 94 91 ± 2.3	55 – 68 62 ± 4.8
VII Casein	1.5 – 3.4 2.5 ± 0.50	21 – 47 35 ± 7.0	2.01 – 2.55 2.36 ± 0.21	10.4 – 18.8 14.5 ± 2.4	104 – 221 206 ± 38.9	12 – 37 21 ± 7.8	49 – 73 65 ± 7.4	0.7 – 1.3 1.0 ± 0.19	1.2 – 2.0 1.6 ± 0.2	110 – 140 130 ± 9.9	83 – 95 90 ± 3.8	60 – 70 66 ± 2.8

*(ingested N)−(faecal + urinary N)

RESULTS AND DISCUSSION

The results are shown in Table II.

The proportion of the ingested nitrogen which is absorbed is a measure of the digestibility of a protein. The figures for this show that digestibility is high, and the same, for egg albumin, casein, and the protein of fish flour.

Morrison and Campbell (1960) obtained *protein efficiency ratios* of 3.80 and 3.04 for fish flour and casein respectively when they were fed at levels to supply 10% protein in the diets. If our figures for Groups I–III are expressed in the same way, *i.e.* as grams weight gain per gram protein ingested, they are 3.3, 3.2, and 2.7 for fish flour, egg albumin, and casein respectively. The ratio of the value for fish flour to casein is 1.25 in their test and 1.22 in ours, which denotes agreement. Our figures also show that for this measure of quality fish flour is the same as egg albumin, which is a high-quality protein and often used as a standard in testing.

The figures for nitrogen balance and the proportion of the absorbed nitrogen retained indicate that the protein of fish flour is intermediate between egg albumin and casein. In both cases the average figure for the fish protein is 90% of that for egg albumin and 110% of that for casein. In the case of the proportion of the urinary nitrogen in creatinine, corresponding figures are 70% and 150%.

The *essential amino acid index* (Oser, 1959a) of a protein or a food which contains protein is in many cases proportional to its *biological value* (Oser, 1959b). When these indices are calculated from the amino acid composition of fish flour (Guttmann and Vandenheuvel, 1957) and of egg albumin (Block and Bolling, 1951) they are 92 and 102 respectively, and are therefore in accord with the *biological values*.

The quality as protein of the visceral and liver meals was very different from that of the muscle preparation.

The appropriate figures in Table II indicate that the nitrogenous constituents of the visceral meal were highly digestible, and the same as egg albumin and casein in this regard. The digestibility of the liver meal, however, was considerably poorer.

Growth was negligible when the visceral meal supplied the nitrogen. The liver meal was better in this respect, despite its poorer digestibility, but nevertheless growth was very poor. The difference between these two preparations in their ability to support growth is shown in their *protein efficiency ratios*, which are both far lower than those of egg albumin and casein. In *biological value* they are essentially the same, and in this measure of quality they do not differ so greatly from egg albumin and casein.

The figures for the percentage of the urinary nitrogen in creatinine are consistent with the *biological values* of fish flour, egg albumin, and casein, but they are not in the case of the liver and visceral preparations. This index cannot therefore be used as a measure of the protein quality of these preparations.

The information which we have obtained does not necessarily define the value of the liver and visceral meals under conditions where they might be used

in animal diets in conjunction with other sources of protein or nitrogen. These data indicate that their nitrogenous constituents are in themselves of poor quality as protein or protein substitutes, and as sole sources of nitrogen will not adequately support animals with dietary requirements for certain preformed (essential) amino acids.

SUMMARY

Standard tests with young rats were applied to investigate the digestibility and the nutritional quality as protein of dried, defatted cod and haddock muscle (fish flour), cod and haddock visceral meal, and cod liver meal. Egg albumin and casein were used as reference proteins.

The apparent digestibility (proportion of the ingested nitrogen absorbed) of fish flour and visceral meal was high, and the same as that of egg albumin and casein. That of liver meal was about 9% lower.

The *protein efficiency ratio*, a measure of the promotion of growth by a given quantity of nitrogenous material, was the same for fish flour and egg albumin, and was 20% lower for casein. The *biological value*, a measure of the retention of the nitrogen absorbed from digestion, was for fish flour 10% lower than that for egg albumin and 10% higher than that for casein. These values establish the protein of fish flour as among the best in nutritional quality.

The *protein efficiency ratios* of casein, liver meal, and visceral meal respectively were 23, 70, and 88% lower than that for egg albumin. For the same materials in the same order, nitrogen balance [ingested nitrogen−(faecal + urinary nitrogen)] were 11, 49, and 46%, and measures of *biological value* were 8, 20, and 14% lower than those for egg albumin. Such values indicate that the liver and visceral meals are of poor quality, and unacceptable as sole sources of protein or as protein substitutes for animals with dietary requirements for certain essential amino acids.

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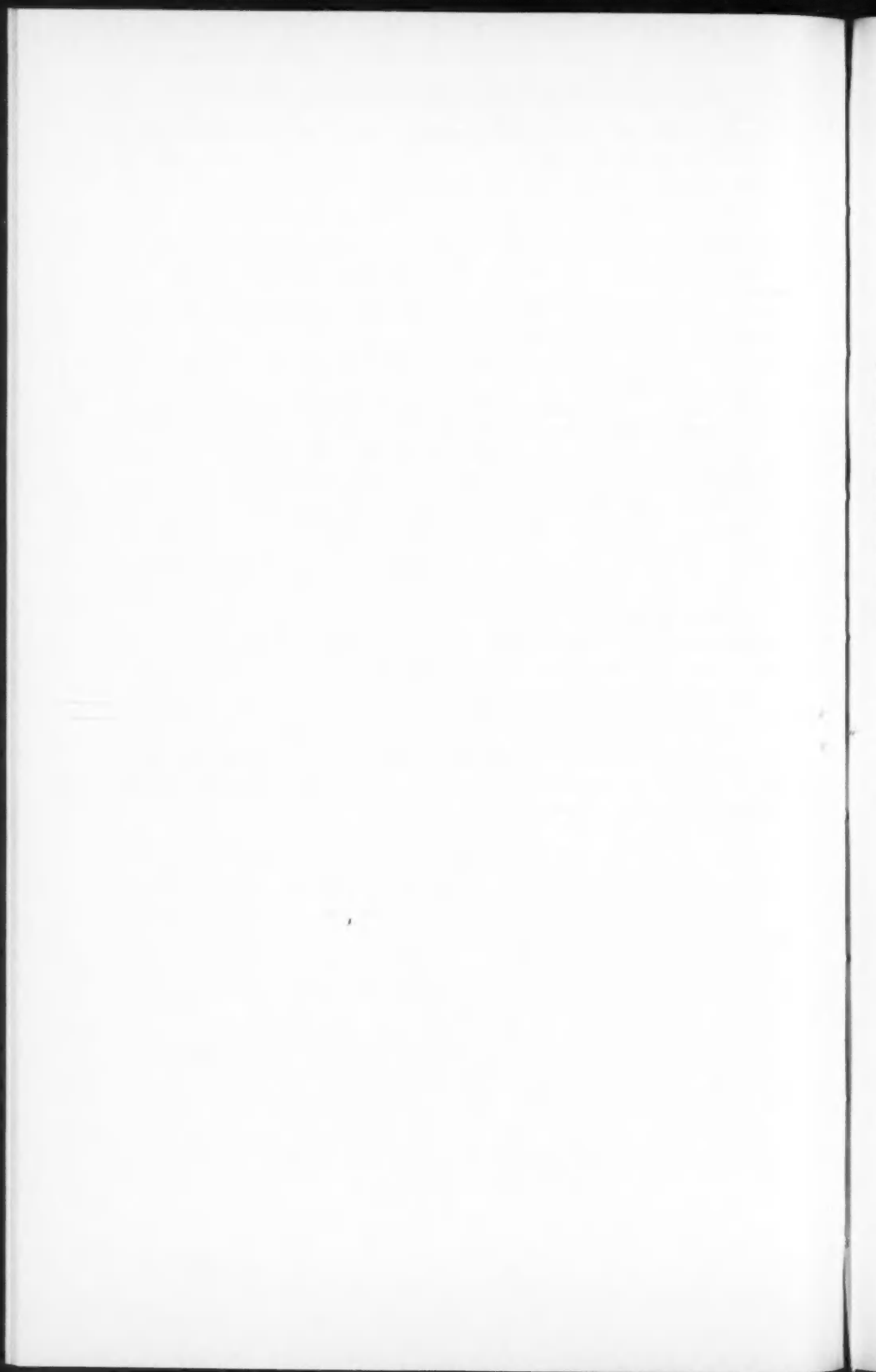
The Liquefaction of British Columbia Herring by Ensilage, Proteolytic Enzymes and Acid Hydrolysis[1]

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ABSTRACT

Nearly all the herring landed on the British Columbia coast during the past 10 years has been converted by the wet reduction process to animal feed, the bulk of which was in the dry form. While the final products of the wet reduction process have proven to be of a high nutritive value, in the dry form they have the disadvantage in the amount of handling required during transit. A liquid product would not only reduce handling costs but also it would act as a binder in otherwise dry feed rations.

Three methods have been tested to liquefy the whole herring: ensilage, high pressure steam liquefaction and proteolytic enzyme solubilization. In the ensilage process the liquefaction of the whole fish in an acid medium was achieved in 72 hours at 37°C. The liquefaction of the fish was shown to be due to proteolysis by the natural occurring enzymes present both in the viscera and in the flesh of the fish and was not caused by the action of bacteria. While up to 70% of the whole fish was solubilized by autoclaving the fish in an acid medium, the resulting free oil was high in free fatty acid content and the liquid concentrate·dark in colour. Of the commercial proteolytic enzymes tested, pepsin achieved the highest maximum solubilization, followed by bromelin and Rhozyme B-6. An oil–protein emulsion stable at 100°C and to salting, however, was formed in the digest of each enzyme tested.

Liquid fish products were prepared under pilot-plant conditions for future nutritional assay.

GENERAL INTRODUCTION

Approximately 200,000 tons of herring were landed in British Columbia during 1958–1959 and almost all of the catch was converted to animal feed. The wet reduction process currently used in British Columbia to bring about the conversion of herring to animal feed yields oil, solubles, meal and whole meal (MacLeod, 1959). Previous studies conducted in these laboratories have been concerned with problems encountered during the conversion of fish (principally herring) stickwater to solubles (McBride *et al.*, 1959).

Herring meal is of high nutritive value and is widely used as a protein and growth factor source in animal feeds. There are certain advantages, however, to having a supplement to animal rations in a liquid rather than in a solid form. In a liquid form it can be more readily transported in bulk in tank cars than is the case with the dry product. Secondly, there are certain advantages to having such a substance as a binder in otherwise dry rations. Thirdly, it should be possible theoretically to prepare a liquid product more cheaply than a dry one since less steam would be required for its preparation. One disadvantage to a liquid product would be the transportation of the water in the final product.

Three methods have been proposed in the past to liquefy fish. In the ensilage process, first introduced in Finland in 1920, minced fish is acidified to pH 2.5 to

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4.0 and allowed to stand for a period of approximately 2 weeks during which time liquefaction occurs (Petersen, 1951). This process, although referred to loosely as ensilage, is actually, as will be shown in this report, a liquefaction of fish resulting from natural enzymes present in the fish. This has been a popular product in Europe, especially the Scandinavian countries, for many years. Published reports indicate that the process is cheap and the product is of good quality (Hanson and Lovern, 1951).

True ensilage differs from this in that the breakdown is accomplished by the action of lactic acid bacteria in a process strictly comparable to the fermentation which takes place in a silo. The true ensilage procedure as applied to fish has been studied to a limited extent in France (Kreuzer, 1954). In another, patented process (Ryan and Wilson, 1952) fish and fish waste is liquefied by the application of steam under high pressure. The use of proteolytic enzymes to digest the fish has also been suggested but no report of a thorough investigation using these enzymes has been made. Freeman and Hoogland (1956) studied the acid and proteolytic ensilage of cod and haddock offal.

Our previous studies of problems associated with herring reduction have been extended to include an investigation of the preparation of liquid fish products from British Columbia herring. Previous studies by Tarr et al. (1953) showed that neither acid autolysates nor bacterial fermentation products prepared from whole herring promoted chick growth more effectively than did commercial herring meal. To approach the problem systematically it was decided to first prepare products from British Columbia herring by the established procedures, to evaluate these products, and then to determine if necessary how such procedures could be modified or new procedures devised which would give the best liquid herring product from the standpoint of cost of production, nutritive value and physical properties.

I. ENSILAGE

MATERIALS

In order to ensure uniformity of starting material for all studies, a large sample of fresh, whole herring caught in November 1958 was stored at −20°C.

METHODS

In each study of herring, whether whole or eviscerated, were ground in a meat grinder to a crude pulp. In order to facilitate pH adjustment of the pulp, one-fifth of its volume of distilled water was added and thoroughly mixed into the homogenate. The pH in each instance was adjusted at 24-hour intervals to the zero time level until the termination of the experiment. Two procedures have been suggested for the liquefaction of herring by this procedure. In one, the pH is adjusted to 2.0 with a strong acid such as HCl or H_2SO_4. In the other, the pH is adjusted to and maintained at 4.5 with formic acid (Hanson and Lovern, 1951). Both procedures were investigated here. As a crude measurement of solubilization pH and viscosity values were determined over a 20-day period. At the completion of each experiment the product was filtered through

two layers of cheesecloth and the solids removed by filtration were then dried and weighed. After the filtrate had settled overnight in a separatory funnel, the top layer of oil was removed and discarded. The sample was then concentrated in a vacuum flash evaporator, the distillate being trapped in a flask placed in a dry-ice–acetone bath. In order to minimize the effect of heat on the final product the temperature of the water bath was kept within the range 25 to 30°C. Suitable aliquots of the concentrate were taken for viscosity determinations. Stormer viscosity determinations were carried out following a 30-minute standing period at 25°C (Rigg and Carpenter, 1912) while the pour residue test, expressed as percentage retained was determined after a setting-up period of 24 hours at 10°C (McBride *et al.*, 1959).

RESULTS AND DISCUSSION

It is evident from an examination of the rate of digestion of Samples 1A and 1B, listed in Table I, that the solids breakdown is at least initially greater when the sample is held at pH 2.0 than at pH 4.5. At the end of the twentieth day, however, the viscosity levels of the two samples are about equal. In order to test the effect of a higher temperature on the rate of solids breakdown, a second experiment was carried out at the same pH levels used in the first experiment at a temperature of 37°C. In this study, Sample 2B displayed a greater initial rate of protein breakdown at pH 2.0 than did Sample 2A at pH 4.5. Both samples, however, showed considerable solids destruction at the end of the first 24 hours of incubation. Again, by the twentieth day of digestion, only slight if any differences existed in the viscosity of the two samples.

Samples 3A and 3B listed in Table I illustrate that the ensilage of herring is due to the natural enzymes of the herring. When as in Sample 3B the herring homogenate is first heated to 95°C for 15 minutes to destroy any naturally

TABLE I. Effect of temperature and pH on the rate of solids breakdown in the production of whole and eviscerated herring ensilage.

Sample No.	Ensilage Treatment	Stormer values during ensilage[a] Time (days)								
		0	1	2	3	4	5	10	15	20
1A	Whole herring, pH 4.5, 25°C	*	*	*	29.6	17.8	17.1	15.5	14.8	14.1
1B	Whole herring, pH 2.0, 25°C	*	32.8	16.5	15.5	15.4	14.2	14.0	13.1	13.1
2A	Whole herring, pH 4.5, 37°C	*	21.2	16.8	15.1	14.8	14.2	13.4	13.3	13.3
2B	Whole herring, pH 2.0, 37°C	*	15.1	13.1	13.1	13.0	13.1	13.1	13.1	13.1
3A	Whole herring, pH 4.5 room temperature (21°C)	*	99.0	28.6	24.5	21.1	20.0	17.0	16.5	15.1
3B	Whole herring heated to 95°C for 15 min before incubation conditions same as 3A	*	*	*	*	*	*	*	*	*
4A	Whole herring, pH 4.5, 25°C	*	*	*	76.1	32.1	21.1	15.5	15.0	14.0
4B	Eviscerated herring, pH 4.5, 25°C	*	*	*	*	46.4	27.7	17.2	16.1	15.5

[a]Sec/100 revolutions at 25°C.
*In excess of 150 seconds.

occurring enzymes, there is little or no change in the viscosity of the resulting product on incubation. On the other hand in Sample 3A, where no heat was applied, there is a continual breakdown of the protein during the course of the incubation.

In order to ascertain whether the protein digestion was due solely to visceral enzymes or whether flesh enzymes also took part in the solids breakdown, an experiment was conducted in which the rate of breakdown of whole herring was compared with that of herring of the same batch from which the viscera had been removed. The results, Samples 4A and 4B, Table I, show that although the whole herring liquefied faster than the eviscerated ones, there was surprisingly little difference between the two samples. Much proteolytic enzyme activity must thus reside in the flesh (Siebert, 1958; Asakawa and Suda, 1957). Although the liquefaction of fish was proceeding at such a low pH that it was unlikely bacterial action could have contributed significantly to the process involved, in view of the name attached to the process and of the possibility of confusing the digestion with a true ensilage fermentation, bacterial counts were made on the digestion mixture at the beginning of a digestion at pH 2, during the course of the digestion and at the end. The system was discovered to be essentially free of bacteria on each test. It has thus been established that under the conditions used, bacteria play no part in the liquefaction process. There were no moulds visible.

The products obtained following digestion contain undigested solids and have a relatively high water content (70 to 80%). Both are undesirable from a commercial standpoint. In an attempt to overcome these disadvantages the products following complete digestion were filtered and then concentrated to a level of 45 to 50% total solids.

The proximate analysis and viscosity values of the concentrates along with the dry weight of the solids removed by filtration are shown in Table II. The amount of solids removed by filtration of the ensilage digest, except for Sample 4B, were all within the range of 15 to 25 g. In the case of Sample 4B, where

TABLE II. Viscosities and proximate analysis of herring ensilage concentrates.

Sample No.	Stormer[a]	Filtered solids (dry weight)	Total solids	Retained	Protein	Oil
		grams	grams	%	%	%
1A	16.5	19.82	45.1	100.00	27.5	10.20
1B	16.5	15.31	45.2	2.8	29.4	4.74
2A	17.7	25.61	48.0	5.3	33.4	3.68
2B	19.2	20.88	50.6	11.5	31.0	5.84
3A	17.3	21.16	44.4	100.00	26.2	9.05
3B[b]	–	–	–	–	–	–
4A	48.8	20.05	44.6	98.3	30.0	6.55
4B	35.1	54.14	43.9	91.7	25.0	15.80

[a]Sec/100 revolutions at 25°C.
[b]Sample not concentrated.

eviscerated herring was used, considerably more undigested solids were removed by filtering.

Although all the concentrates listed in Table II except Samples 4A and 4B indicated satisfactory Stormer values of under 30 seconds, only Samples 1B, 2A and 2B gave good pour residue tests. The high percentage retentions found in Samples 1A, 3A, 4A and 4B can be explained in part by the high oil contents in these samples. Herring oil, present as a protein–oil emulsion in these samples, solidifies at 10°C, the temperature used for pour residue determinations.

Although the initial results obtained to date would suggest that this procedure has many possible merits it has, however, one obvious demerit from a commercial viewpoint. The length of time required to obtain sufficient digestion would make it necessary to have a considerable number of large-capacity digestion tanks for an operation of any considerable size.

II. PROTEOLYTIC ENZYMES

In the previous section the use of naturally occurring proteolytic enzymes of the herring has been shown to give rise to a product which has some very desirable characteristics. Unfortunately, however, the process is slow. The most obvious way of increasing the rate of digestion is to add more enzymes. This has been considered and tested in the past by others but no report of any detailed study has been published.

The initial phases of this study were focussed on determining the capacity of several commercially available proteolytic enzymes to reduce whole herring with maximum solids breakdown to a suitable liquid product.

PRE-HEATED HOMOGENATES

Since it is generally accepted that proteolytic enzymes other than collagenases do not attack collagen but do attack gelatin, and since collagen is converted to gelatin by heat, it was of interest to determine the relative effect of the proteolytic enzymes used in these studies on heated and unheated herring.

PROCEDURE

A 500-g sample of whole herring homogenate was used in each instance. To this was added 225 ml of distilled water to facilitate pH adjustment. The enzymic level selected was 0.5% of the wet weight of the undiluted herring homogenate, and the digestion time was held to 180 minutes. In all instances the substrate was agitated continuously by stirring and the pH maintained at the desired optimum level during digestion. The pH level and temperature of digestion selected for each enzyme were the optimum levels indicated by the manufacturer of the enzyme under investigation. When the substrate was preheated this was carried out at 95°C for 10 minutes. The course of enzyme digestion was followed by noting the amount of acid required to maintain the pH constant. Following the completion of enzyme digestion each substrate was

heated in a boiling water bath for 15 minutes to insure enzyme deactivation. Upon cooling the substrate was filtered through two layers of cheesecloth. The solids removed by filtration were dried and weighed. The filtrate was then allowed to settle overnight and the top oil layer removed. Again, in order to minimize the effect of heat on the final product, the filtrate was concentrated in a flash evaporator under vacuum. The distillate was collected in a flask placed in an acetone–dry-ice bath while the temperature of the water bath was kept within the range of 25 to 30°C.

RESULTS AND DISCUSSION

The course of digestion as indicated by the amount of acid required to maintain the pH constant during digestion of both heated and unheated herring is shown in Fig. 1, using pepsin as the test enzyme. It is evident that for this enzyme proteolysis was both more rapid and more complete when preheated herring was used as the substrate. With the precooked substrate, digestion was essentially complete in 90 minutes, while with the unheated fish, levelling off of digestion occurred only after 170 to 180 minutes of incubation. The other
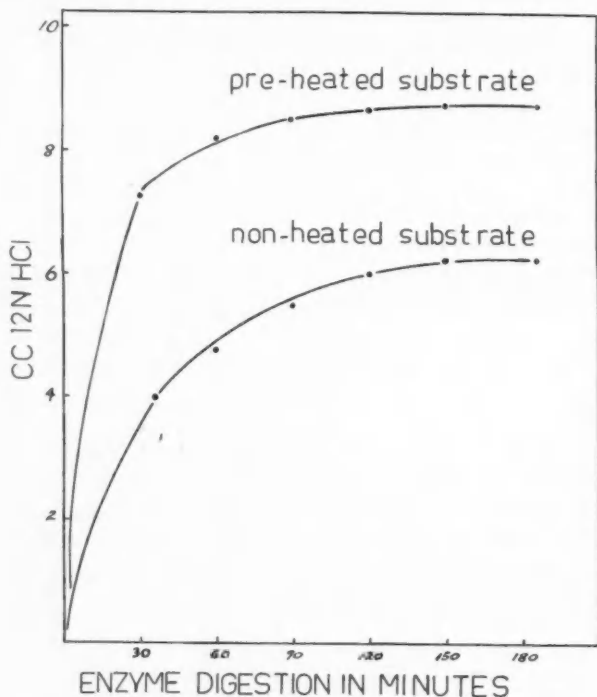
FIG. 1. Rate of pepsin proteolysis in pre-cooked and non-cooked herring homogenate.

enzymes tested, Rhozyme B-6 and protease, gave similar pH titration curves and digestion appeared to be complete in similar lengths of time.   When the products from the different enzymes were examined further and concentrated, however, differences in the effects of the enzymes were apparent.   The amounts of undigested material recovered from each treatment are recorded in column 4 of Table III.   When the digests from the unheated fish were filtered the Rhozyme

TABLE III. Effect of several commercial proteolytic enzymes in the reduction of pre-heated and not-pre-heated whole herring to liquid fish.

Sample No.	Enzyme[e]	Substrate treatment	Protein in filtered solids
			grams
1A	Protease	Pre-heated	2.97
1B	Protease	Not heated	3.07
2A	Rhozyme B-6	Pre-heated	17.2
2B	Rhozyme B-6	Not heated	22.2
3A	Pepsin	Pre-heated	1.67
3B	Pepsin	Not heated	3.87

[e]Enzyme digestion at the following pH and temperature: Protease pH 8.0, 50°C; Rhozyme B-6 pH 6.0, 60°C; pepsin pH 2.0, 37°C.

B-6 digest showed the greatest, and pepsin the least, amount of undigested protein.   Precooking increased the amount of protein digestion in all cases.

ENZYMIC SOLUBILIZATION OF PREHEATED SUBSTRATES

INTRODUCTION

When the amount of acid or alkali required to maintain the pH constant during enzyme digestion is used to measure the extent of proteolysis, very rapid changes are observed to occur in the first 2-hour period, after which time the activity levels off.   At this levelling-off point, however, solubilization of the substrate is by no means complete.   The following experiment was designed to determine the degree and rate of solubilization that could be achieved.

PROCEDURE

For each experiment the substrate consisted of 1000 g of whole herring homogenate, the proximate analysis of which had been pre-determined.   To this was added 500 ml of distilled water to facilitate pH adjustment.   In each study the substrate was denatured prior to enzyme digestion by heating the diluted homogenate in a water bath to 85°C for 15 minutes.   The enzyme level selected was 0.5% of the wet weight of the undiluted herring homogenate.   In all instances the substrate was agitated continually by stirring and the pH maintained at the desired optimum level during digestion.   The pH level and temperature of digestion selected for each enzyme were the optimum levels indicated by the

manufacturer for the enzyme under investigation. The digestion was allowed in each case to continue until no further increase in the percentage solubilization of the substrate was evident. Solubilization of the substrate was determined as follows: A 60-ml aliquot was taken, 10 ml being used to determine the total solids content of the whole substrate, while the remaining 50 ml was centrifuged at 20,000 × g for 20 minutes. Following centrifugation, the oil which had collected at the surface was removed and the total solids content of the clear supernatant water-soluble fraction was determined. This value, coupled with that for solids minus the oil of the uncentrifuged sample, was then used to determine the percentage solubilization achieved by the enzyme.

At the completion of each enzyme digestion the substrate was centrifuged at 20,000 × g, the insoluble solids were collected, dried at 80°C in a vacuum oven and weighed. Also, a suitable aliquot of the oil that had been freed at the surface was taken for free fatty acid determinations, The free fatty acids were determined by the method outlined in the Official Methods of the American Oil Chemists Society and expressed as oleic acid.

RESULTS AND DISCUSSION

The data in Table IV show that pepsin gave rise to the highest percentage solubilization while Rhozyme B-6 and bromelin were about equally active. While both pepsin and bromelin achieved maximum solubilization at the end of 48 hours

TABLE IV. The effect of several commercial proteolytic enzymes on the reduction of whole herring to liquid fish.

Enzyme	Proximate analysis of the original whole herring			Enzyme digestion conditions			Insoluble solids (dry weight)	Maximum solubilization	Free oil	Free fatty acids in free oil
	Protein (N × 6.25)	Oil	Water	pH	Temp	Time[d]				
	%	%	%		°C	hours	grams	%	%	%
Pepsin	16.40	13.16	67.10	2.0	37	48	56.14	77.8	15.0	10.80
Bromelin	16.38	13.14	67.18	4.5	60	48	88.47	64.6	18.0	7.6
Rhozyme B-6	16.44	13.20	67.05	6.0	60	72	92.34	65.5	12.0	9.7[e]

[d]Time required for maximum solubilization or point experiment terminated.
[e]Free fatty acid level following 48-hr digestion 7.2%.

of digestion, Rhozyme B-6 required an additional 24-hour digestion period to reach its highest level of solubilization. The results for pancreatin and protease digestion were not included in Table IV as both were unsatisfactory due to the fact that a thick oil–protein emulsion formed when these enzymes were used. The digestion conditions for the latter two enzymes were as follows: pancreatin, pH 7.8, 37°C; protease, pH 8.0, 40°C. The pancreatin digestion lasted for 91 hours while the protease digestion was terminated at the end of 48 hours. It is of interest that both these enzymes had optimum pH levels on the alkaline side of neutrality while the remaining enzymes tested had optimum pH levels on the acid side. Whether this difference in the optimum pH level had any effect on the formation of the emulsion is not known. Nevertheless, as the pH optimum of the enzyme

went down, the ability of the enzyme to solubilize the herring increased. The oil–protein emulsion formed was found to be present in all the enzyme-digested samples but to a much smaller extent in those where the enzyme used had an optimum pH below neutrality, in which cases the emulsion accounted for only 15 to 20% of the total volume of the digest prepared. The emulsion formed a layer immediately below the free oil, solidified at temperatures below 10°C and could be easily separated mechanically without contaminating the clear fraction below. Analysis of two of these emulsions on a wet-weight basis, one taken from a completed bromelin digest and the other from a completed pepsin digest, showed them to have a protein level of from 15.2 to 15.8% and an oil level of 30.8 to 31.1%.

The results given in Table I also show that the lowest quantity of insoluble solids was obtained from the pepsin digest and the highest amount from the Rhozyme B-6 digest with the bromelin digest giving a yield somewhat less than that obtained from the Rhozyme B-6 sample. These values agree with the results expected on the basis of the percentage solubilization obtained with the respective enzymes. The proximate analysis of the raw herring homogenates showed no apparent differences. This can be attributed to the fact, as previously mentioned, that the herring used in this investigation were all taken from a single November 1958 catch.

The free fatty acid levels of the free oil obtained at the completion of 48 hours of enzyme digestion varied inversely with the digestion pH.

Oil–protein Emulsion

As previously noted, the main difficulty encountered following the completion of the enzyme digestion is the removal of oil prior to the concentration of the digest to the finished product. On centrifuging, only a small fraction of the oil separates as free oil; the rest appears in the form of an oil–protein emulsion. If the oil in the oil–protein emulsion is allowed to remain in the final product, the product is very viscous at low temperatures. Furthermore, if the oil content of the finished product exceeds 5% on a wet-weight basis, the product would normally be considered unacceptable as a feed supplement.

As mentioned earlier, while it is possible to remove the oil emulsion mechanically by chilling the product and scraping off the solidified emulsion, this process in a commercial operation might be both cumbersome and uneconomical.

In order to study this emulsion problem further, a large pool of bromelin-solubilized liquid digest, which had not been centrifuged, and hence from which the free oil had not been removed, was prepared as outlined in Table IV. This product was divided into three equal parts and one of each of the parts was diluted with distilled water to a total solids content as follows: Part A, 18%; Part B, 12%; Part C, 6%. Using 100-ml graduates and 50-ml aliquots of the diluted digests, each test solution was subjected to a series of treatments in an attempt

to obtain maximum recovery of free oil. The procedures followed and the results obtained are given in Table V. The volumes of oil were determined after the test solutions had stood at room temperature for 24 hours following completion of the treatment.

TABLE V. Effect of autoclaving, heating to 95°C and salting on the release of free oil in solubilized liquid fish solutions of varying total solids content.

Treatment	Sample	Total solids	Total oil present	Free oil following treatment	Free oil
		%	ml	ml	%
1. Autoclaved for 30 min	A	18	9	7	77.7
at 15 lb/sq in	B	12	6	4	66.6
	C	6	3	2	66.6
2. Heated to 95°C for 30 min	A	18	9	1	11.1
	B	12	6	1	16.6
	C	6	3	0.5	16.6
3. (i) 10 mg KH_2PO_4 added	A	18	9	2	22.2
(ii) Heated to 95°C for	B	12	6	4	66.6
10 min	C	6	3	2	66.6
4. As in No. 3 except 50 mg	A	18	9	3	33.3
KH_2PO_4 added	B	12	6	3	50.0
	C	6	3	2	66.6
5. As in No. 4 except heated	A	18	9	1	11.11
to 95°C for 30 min	B	12	6	4	66.6
	C	6	3	2	66.6

Up to 77.7% of the total oil was released as free oil upon autoclaving for 30 minutes while only 66% of the total oil existed as free oil following 30 minutes of boiling even after the addition of KH_2PO_4. While diluting, the digest appeared to have little effect in promoting the release of oil in the autoclave treatment; the more dilute preparations yielded a higher percentage of oil in the other four treatments. From these results it is evident that the emulsion present after enzyme digestion is a very stable one and methods other than heat or salting out will have to be found to break it satisfactorily. It was reasoned, however, that by removing the greater portion of the total oil from the herring by a pre-press as is done in the present commercial reduction process, the emulsion problem might be successfully eliminated. To test this possibility an experiment was carried out where the denatured herring homogenate was pre-pressed prior to enzyme digestion. The diluted denatured herring homogenate was placed in a double-layer No. 12 canvas bag and pressed at 5,000 lb/sq inch. The press juice released was collected, transferred to a separatory funnel and allowed to stand overnight at room temperature. The free oil which separated was removed, the volume measured and the free fatty acid concentration determined. The water layer of the press liquid was added back with thorough mixing to the press pulp. The reconstituted mixture minus the free oil was digested with pepsin for 48 hours. After digestion the mixture was centrifuged, and the degree of

solubilization, the amount of free oil, its fatty acid content and the amount of emulsion present was determined. A record of the observations is given in Table VI.

TABLE VI. Effect of mechanical pressing followed by pepsin digestion on the release of free oil in a denatured herring homogenate.

Fraction	Oil recovery in the various fractions[f]
Free oil	57.5
Oil–protein emulsion	31.6
Insoluble solids	10.9
Liquid digest	0.0

[f]Expressed as percentage of oil present in the original herring.

Although all the oil was not removed by pre-pressing, the amount removed (57.5%) suggests that this method does offer a possible means of at least partially by-passing the emulsion problem, particularly since under industrial conditions, where more efficient presses are employed, pressing of the cooked herring removes up to 85% of the total oil present. Furthermore, the oil obtained from the press juice was of excellent quality with a free fatty acid level of only 1.4% as compared to 7 to 10% for the free oil obtained following the enzyme solubilization of whole fish.

Upon centrifuging a suitable aliquant of the 48-hour pepsin digest of the pressed fish, it was noted that none of the remaining oil in the substrate was present as free oil. The remainder of the oil was found to be bound almost completely in the oil–protein emulsion, which accounted for approximately 10% of the total digest volume. This emulsion which on a wet-weight basis had an oil level of 30.1% contained 31.6% of the total oil present in the original herring homogenate. By calculation, the insoluble solids which would contain the remainder of the total oil in the fish held 10.9% of the oil present in the herring homogenate.

The 73.9% solubilization obtained at the end of 48 hours pepsin digestion compared favourably with previous results for non-pre-pressed substrates.

INSOLUBLE SOLIDS

It has been found that 20 to 30% of the original fish fails to be solubilized on enzyme treatment (Table VII). The insoluble solids from a pepsin digest were hydrolysed in a sealed combustion tube with $6N$ HCl. Analysis for free α-amino nitrogen revealed that after hydrolysis 69% of the total nitrogen was α-amino nitrogen, indicating that most of the nitrogen in the sample was present as protein nitrogen. It seemed not unlikely that failure to get more complete solubilization of the protein would be due to inhibition of the action of the digestive enzyme by accumulation of the products of hydrolysis. In order to test

TABLE VII. The insoluble solids content of liquid fish prepared by maximum enzyme solubilization of whole herring homogenates.

Enzyme	Substrate (dry weight)	Insoluble solids (dry weight)	Analysis insoluble solids	
			Protein	Oil
	grams	grams	%	%
Pepsin	329	56.14	66.10	19.6
Bromelin	329	88.47	66.50	12.6
Rhozyme B-6	329	92.34	63.50	15.15

this hypothesis and to make an effort to reduce the size of the insoluble fraction still further, a series of experiments was carried out in which the insoluble solids obtained following maximum solubilization were separated from the digestion mixture and subjected to fresh enzyme attack.

In the first experiment, a 48-hour pepsin digest of herring homogenate prepared as outlined in Table I was divided into two equal parts. One part was held without further treatment to serve as the control. The second part was centrifuged at $20,000 \times g$ for 20 minutes. The insoluble solids were collected and resuspended in 100 ml of distilled water. Both the control and the re-suspended solids were adjusted to pH 2.0 and placed in a water bath at 37°C. To the resuspended solids was added a slurry of fresh pepsin at a level equal to one-half the amount used in the original digestion, that is, 0.25% of the total weight of the undiluted herring homogenate. The solubilization of both samples was followed until no further change was noted. The results obtained from this study are given in Table VIII, Experiment No. 1. The second experiment was

TABLE VIII. Effect of further pepsin digestion on the insoluble solids obtained from a maximum solubilized pepsin and Rhozyme B-6 digestion of whole herring.

Experiment No.	Initial maximum enzyme solubilization			Conditions and results of further treatment on the insoluble solids				Analysis of insoluble solids obtained from second digestion	
	Enzyme used	Digestion time	Solubi-lization	Enzyme added	Digestion time	Further solubi-lization[b]	Total[a] solubili-zation	Protein	Oil
		hours	%		hours			%	%
1. Part A (control)	Pepsin	48	77.8	–	48	0.6	78.4	66.1	19.6
Part B (test)	Pepsin	48	77.8	Pepsin	48	8.1	85.9	65.1	24.8
2. Part A (control)	Rhozyme B-6	72	67.7	–	48	7.1	74.8	69.0	16.6
Part B (test)	Rhozyme B-6	72	67.7	Pepsin	48	18.2	85.9	57.0	23.2

[a]This represents the sum of the solubilization which occurred during the initial digestion and the solubilization which resulted from further treatment of the insoluble solids.
[b]Expressed as percentage of the total solids present at the beginning of the first digestion.

designed to establish whether the lower degree of solubilization achieved with Rhozyme B-6 as compared to pepsin was a pH rather than an enzyme effect. Since more bone would be solubilized at pH 2 than at pH 6, the larger amount of insoluble solids at the higher pH might merely mean a lesser dissolution of bone.

In the second experiment the insoluble solids from a Rhozyme B-6 digest were divided into two equal lots and each was suspended in a volume of distilled water equal to one-half the original digest volume. Following the adjustment of both samples to pH 2.0, the products were placed in a 37°C water bath. One sample, the control, was held without further treatment. To the other was added a slurry of pepsin at a level equal to 0.25% of the original weight of the un-diluted herring homogenate. Solubilization was followed in each sample until no further change was evident. The extent of solubilization achieved is shown in Table VIII under Experiment No. 2.

Examination of the results listed in Table VIII show that the greatest additional solubilization was obtained when the insoluble solids from the Rhozyme B-6 digest were subjected to pepsin digestion. It is evident that much, but not all, of this solubilization occurred as a result of adjusting the insoluble solids suspension from pH 6 to pH 2 and hence would represent solubilization of bone. It is evident, however, that pepsin still has a somewhat greater capacity than Rhozyme B-6 to solubilize the herring, an effect which is independent of the pH of the digestion system.

The ability of fresh pepsin to further digest a suspension of insoluble solids which had been freed of components of the original reaction mixture suggests either that the reaction products inhibited further digestion or that the original pepsin had lost its activity and a supply of fresh enzyme was required to produce further solubilization.

The results obtained thus far on the rate and extent of solubilization of the whole fish clearly indicate that pepsin is the superior of the enzymes tested. On the basis of this finding the following experiments were limited to a study of pepsin.

OPTIMUM pH LEVEL FOR PEPSIN ACTIVITY

Evidence has been presented elsewhere that the optimum pH for pepsin activity on denatured bovine serum albumin and haemoglobin is 3.5 as compared to an optimum pH of 1.7 for the corresponding native substrates (Schlamowitz and Peterson, 1959). Although the results for pepsin activity presented here have all been carried out at pH 2.0, it would be highly desirable from a commercial point of view if the optimum pH level for pepsin digestion of denatured herring was 3.5. This would not only eliminate the necessity for the expensive alloy equipment required to withstand the acidity of pH 2.0, but also, if the optimum pH for pepsin activity on denatured herring was 3.5, it might shorten the length of the digestion time needed to obtain digestion at pH 2.

To test for the optimum pH for pepsin activity on a denatured herring substrate, three substrates were prepared exactly as outlined in Table IV for pepsin digestion except for the pH levels of the substrates. The pH of the first sample was adjusted to 2.0, the second sample to 3.0 and the third sample to 3.5. The level of pepsin used in each of the three samples was 0.5% of the weight of the undiluted herring homogenate and all three samples were tested simultaneously. A record was kept of the total amount of 12N HCl required to maintain the starting pH levels in each sample. The percentage solubilization

was determined for each sample at the end of 24 hours of digestion. The results are given in Table IX, and show clearly that the pepsin activity is significantly higher at pH 2.0 than at either pH 3.0 or 3.5.

TABLE IX. The effect of pH on the level of pepsin activity as measured by the total amount of 12N HCl used to maintain the desired pH and the percentage solubilization obtained following 24-hr digestion.

Sample No.	pH zero hour	Amount 12N HCl used to maintain a constant pH	Solubilization following 24-hr pepsin digestion
		ml	%
1	2.0	26.8	63.0
2	3.0	16.2	47.1
3	3.5	8.7	38.4

OPTIMUM PEPSIN LEVEL FOR SOLUBILIZING HERRING

The use of 0.5% levels of pepsin, as with the other enzymes studied, was based on the arbitrary suggestion of the enzyme manufacturers rather than on experimental findings using herring as the substrate. To determine the optimum level of pepsin for maximum solubilization an experiment was carried out using three separate substrates, each prepared exactly as before except for the enzyme level tested. The three levels of pepsin selected were 0.1, 0.3 and 0.5%, based on the weight of the undiluted herring homogenate. Again, all three digestions were carried out simultaneously. In this study the change in the pH during
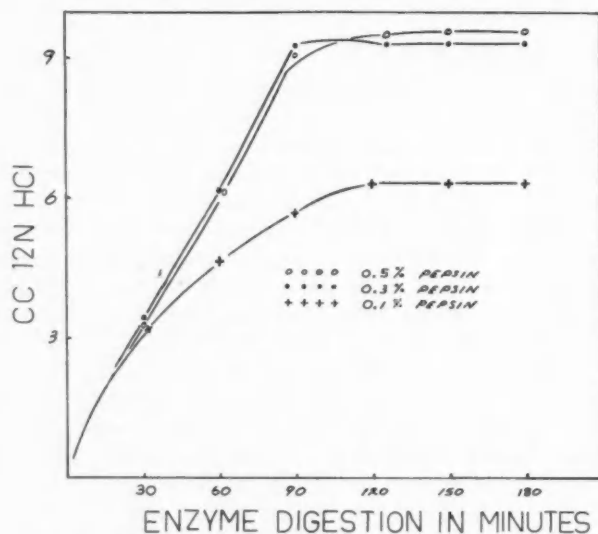

FIG. 2.   Rate of pepsin proteolysis at 0.5, 0.3 and 0.1% enzyme concentrations in denatured herring homogenate.

digestion was used as an index of enzyme activity. The experiment was terminated at the end of 3.5 hours of enzyme digestion. The rate of digestion as indicated by the amount of acid required to maintain the pH constant during digestion is shown in Fig. 2.

It is evident from an examination of the curves given in Fig. 2 that following the initial 20 minutes of incubation the pepsin proteolysis is faster at the 0.3 and 0.5% enzyme levels than at the 0.1% level. There appears to be no apparent difference in the rate of proteolysis at the 0.3 and 0.5% enzyme concentrations.

III. HIGH-TEMPERATURE ACID HYDROLYSIS

LABORATORY STUDIES

The method of using steam under high pressure to liquefy non-fatty fish scraps which have been previously acidified to a pH of 2 to 4 is used extensively on the eastern coast of this continent. Although the process has not been developed to include fatty fish such as herring, the manufacturers using this process claim good physical and chemical properties for their products. As we are not aware of any detailed report on the use of this process with fatty fish, a study of the process was carried out using herring.

The apparatus used in this study to hold the sample under the desired steam pressure consisted of a large monel-alloy cylindrical tank fitted with a removable top. A large stirrer which could be removed when not in use was available for mixing large batches of fish. A closed inside circular steam line was connected to an external steam generator which furnished the required steam pressure at a constant level for the period of the experiment.

In order to test both the operation of the apparatus and the efficiency of the process, a 600-g batch of whole herring homogenate was diluted with 120 ml of distilled water and then adjusted to pH 1.0 with concentrated H_2SO_4. The acidified product, held in a 1-litre beaker, was covered with a large petrie dish and the beaker plus contents suspended by wire in the steam tank. The tank was sealed, brought to a steam pressure of 50 lb/sq in (300°C) for 3 hours and then cooled. The tests used and the results obtained when the cooled product was analyzed were as follows: solubilization, 69.9%; free oil in the total oil, 66.4%; free fatty acids in the free oil, 7.5%. The most significant difference between this product and that prepared by proteolytic enzymes was the complete absence of any oil–protein emulsion in the pressure cooked sample. While the percentage solubilization achieved in this steam-cooked sample was somewhat lower than that achieved in the maximum solubilized pepsin sample, it is, however, higher than that achieved in the maximum solubilized bromelin and Rhozyme B-6 samples. Furthermore, the percentage of the total oil existing as free oil in the pressure sample was approximately 4.5 times as great as in the enzyme-solubilized products. The free fatty acid level of 7.5% obtained in the free oil of the pressure sample did not differ significantly from the levels obtained for the corresponding enzyme products. The steam pressure prepared liquid fish did, however, have a much darker colour than the finished enzyme sample, as well as a slightly burnt odour.

Pilot-plant Studies

This phase of the study was carried out with the collaboration of Mr F. Claggett of this Station.

Normally the pilot plant is used to test the efficiency of the finalized procedures developed in the laboratory under conditions more likely to exist in an industrial plant. This, however, was not possible in the present investigation due not only to the volume limitations of the pilot plant itself but also to the physical nature of the product being handled. As only a few pounds of finished product can be prepared at any one time, the pilot plant is run on a batch basis rather than as a continuous process. In such an operation considerable amounts of the product are lost through numerous transfers in the plant during heating, cooling and centrifuging of the dilute sample. As the finished product is fairly viscous, further losses due to the sticking of the product to the sides of the evaporator and the outlet pipes are incurred during removal of the finished product. These losses make it impossible to obtain accurate quantitative data on the operating efficiency of the plant. The pilot plant was used, however, to prepare pepsin-solubilized liquid fish and pressurized liquid fish in sufficient quantities to be tested at a later date in conjunction with commercial herring solubles, commercial meal and commercial whole meal for their respective nutritive values as a supplement in chicken feed rations.

MATERIALS

The herring used for the production of all five of the products just mentioned was taken from a single commercial "set" in November 1959. The herring selected for enzyme and steam-pressure solubilization were stored in 4-gallon (18-litre) liver cans at 10°F until required for processing. Since the required volume of liquid fish concentrate prepared by each of the two processes greatly exceeded the processing capacities of the pilot-plant equipment, the whole herring were divided roughly into 50-lb batches and processed on a batch basis.

METHODS

For pepsin solubilization the procedure used was as follows: The herring were homogenized with the use of an electrical cutter and then diluted with one-half their weight of distilled water. Denaturation of the sample was accomplished by heating the diluted herring homogenate to 90°C for 20 minutes. To avoid scorching, the homogenate was stirred continuously during heating. Upon cooling, the temperature and pH of the homogenate was adjusted to the optimum for pepsin digestion, that is, to 37°C and pH 2.0. Following the addition to the homogenate of a slurry of pepsin in water at a level equal to 0.5% of the undiluted herring homogenate, digestion was allowed to proceed for a period of 48 hours. At the completion of each enzyme digestion period the substrate was adjusted to pH 4.0 to prevent corrosion of pilot-plant equipment and heated to 99°C to ensure maximum oil separation. The heated substrate was centri-

fuged through a Centriwesta centrifuge twice, first with the chamber bowl to remove insoluble solids and then with the disc bowl to separate the free oil. Both the oil and the insoluble solids removed by centrifuging were collected separately. The insoluble solids were dried at 80°C in a vacuum oven and weighed. The clarified liquid fish was then stored in wide-mouth 4-gallon liver cans at 0°C overnight to facilitate settling and solidification of the oil emulsion. After oil emulsion removal by scraping off the solidified layer, the solubilized liquid sample was concentrated *in vacuo* in a pilot-plant concentrator.

For the preparation of steam-pressurized liquid fish the herring homogenate was diluted as outlined for the enzyme sample with distilled water, adjusted to pH 1.0 with concentrated H_2SO_4 and pressure cooked at 50 lb/sq inch (300°C) for 3 hours with continuous stirring. When cool it was adjusted to pH 4.0 and the oil and insoluble solids were removed by centrifuging as outlined for the pepsin digest. The clarified sample was then concentrated *in vacuo* in the pilot plant.

Each of the products was analyzed for oil, water, ash, protein and total solids. Viscosity tests were carried out on the liquid products.

RESULTS AND DISCUSSION

When the data from the two liquid fish products listed in Table X are compared on a 100% total solids basis to the corresponding results obtained for

TABLE X. Analysis and viscosity tests of a pressure and a pepsin solubilized liquid fish concentrate and comparison of the analyses with that of commercial meal and whole meal.

Analysis (wet weight)	Acid-pressure liquid fish (Station product)		Pepsin-solubilized liquid fish (Station product)		Meal (commercial)		Meal (commercial) (whole)	
	Actual% total solids[i]	100% total solids[i]	Actual% total solids	100% total solids	Actual% total solids	100% total solids	Actual% total solids	100% total solids
Water (%)	57.00	0.00	65.0	0.00	7.70	0.0	7.90	0.00
Total solids (%)	43.00	100.00	35.0	100.00	92.30	100.0	92.10	100.00
Protein (%)	32.90	76.60	22.10	63.10	74.00	80.10	74.50	81.00
Oil (%)	1.91	4.45	5.60	16.00	8.94	9.69	9.42	10.20
Ash (%)	8.22	19.10	6.80	19.40	9.10	9.85	8.32	9.05
Viscosity test Stormer[i]	17.90	–	16.4	–	–	–	–	–

[i]Analyses are given both for the actual solids content of the product as well as for a product calculated to contain 100% solids for ease of comparison with the results for meal.

[i]Seconds/100 revolutions/200 g weight. Test after sample held for 2 hours at 25°C.

the meal and whole meal products, it is evident that the protein content of the two meal samples is somewhat higher than found in the two liquid products. On the other hand, the ash values of the two liquid fish products were approximately equal and about double the ash levels found in the two meal products. While the oil levels of the two meal samples were about equal, the oil content of the pressure-solubilized liquid fish sample was about one-half that found in the two meals and

approximately one-quarter that present in the enzyme-solubilized liquid fish concentrate. These four products, although similar in that each contains the greater portion of the original constituents of the raw herring, do however have some significant differences in their preparation. Meal is that part of the herring obtained in the reduction process following the removal of the press juice. The press juice is kept separate and utilized following the removal of free oil, in the production of herring solubles. Whole meal on the other hand is meal to which has been added a portion of the herring solubles. The amount of solubles added to the meal for the production of the whole meal varies from 10 to 40% depending upon operating conditions and economic demand for solubles as a separate product at the time. As the pre-pressing of herring results in a press juice containing substantial amounts of the total oil and ash present in the raw herring, one would expect the meal sample to contain smaller amounts of these two constituents than would the whole meal. In actual fact the oil content of the meal sample was somewhat lower than noted in the whole meal sample. The ash level of the meal product, however, was slightly higher than the whole meal product.

As a complete removal of the oil–protein emulsion was not accomplished in the liquid enzyme preparation due to mechanical difficulties encountered in working with large volumes of dilute digest, the oil level of this product is significantly greater than that obtained in the other finished products. It is evident from an examination of the proximate analysis of this product that the oil is displacing the protein and not the ash.

Thus, the results obtained for these four products indicate that if each sample is prepared under optimum operating conditions, each product on a 100% total solids basis would have approximately the same protein content. Furthermore, while the ash level in the two liquid fish products would be about double that amount present in the two meal samples, the oil content of the two meal samples would be about double that present in the two liquid fish products.

COMPARISON AMONG PROCESSES

As previously noted, it is not possible to calculate the efficiency of the two liquefaction processes on the basis of the results obtained from the pilot plant operation. It is possible, however, to obtain some idea of their efficiency from the results obtained in the small-scale studies carried out in the laboratory. In Table I are listed the amounts of commercial solubles, commercial meal, commercial whole meal, pepsin-solubilized liquid fish and pressure-solubilized fish plus their respective by-products obtainable from one ton of whole raw November herring. The figures given for meal, whole meal and solubles are based on actual production data obtained from a local fishing company. The liquid fish product results obtained by both pepsin and pressure solubilization have been based on laboratory findings obtained under optimum conditions.

The data in Table XI indicate that whereas in herring reduction to meal the nitrogenous components of the original herring are found in two fractions, when herring is solubilized to a liquid fish product, at least by enzymes, the nitrogen appears in three.   Two of these, the oil–protein emulsion and the insoluble solids,

TABLE XI. A comparison of herring reduction by three methods, enzyme solubilization, pressure solubilization and conversion to meal and solubles from the standpoint of product yield and composition.

Treatment	Products formed	Yield[k]		Components			
		Wet weight	Dry weight	Protein	Ash	Oil	Free fatty acid
		pounds			*pounds*		
Pepsin	Liquid fish	498	249	199	50	0	–
solubilized[l]	Free oil	–	39	–	–	28.2	10.8
	Oil–protein emulsion	450	203	68	–	135	–
	Insoluble solids	408	182	54	42	86	–
Pressure	Liquid fish	446	223	179	44	0	–
solubilized[m]	Free oil	–	207	–	–	199.5	7.5
	Oil–protein emulsion	0	0				
	Insoluble solids	602	380	142	185	53	–
Reduction to whole	Whole meal	–	385	293	36	38	–
meal (10% solubles added back)	Free oil	–	202	–	–	–	1.0
Reduction to meal,	Meal	–	350	259	32	31	–
oil and solubles	Free oil	–	202				1.0
	Solubles	150	75	53	15	7.5	–

[k]Calculations based on the reduction of 2000 lb of November-caught herring containing a total of 320 lb protein, 260 lb oil, and 52 lb ash.
[l]Based on 78% solubilization.
[m]Based on 70% solubilization.

would probably be unsuitable for ordinary feeding purposes.   The product formed in the solubilization process which is comparable with fish meal is the liquid fish fraction itself.   It is clear that in both solubilization processes the recovery of protein is considerably less in this fraction than in fish meal.   Unless this liquid fish fraction can be shown to have a nutritive value which will compensate for its lower protein content, it would appear unlikely that this process would be competitive with fish meal.

In the enzyme but not the pressure liquefaction process, only a small percentage of the total oil is recoverable as free oil and the quality of this is judged by its free fatty acid content is low.   As herring oil is one of the more valuable by-products of herring reduction, this poor oil recovery would be a further disadvantage of the process.

The insoluble solids which separate during oil recovery in the liquefaction processes, unless they can be resuspended in the liquid fish fraction, would represent a considerable loss of the total solids content of the original fish.

It would appear that unless the liquid fish fraction proved to be a really premium product which could demand a special price, it is unlikely that herring reduction by either liquefaction process would be competitive with a fish-meal operation.

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The Protein Nutritive Value of "Liquid Herring" Preparations[1]

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ABSTRACT

Experimentally prepared "liquid fish" made from British Columbia herring was compared with presscake herring meal, whole herring meal and condensed herring solubles as a source of supplementary protein for chicks. Two samples of liquid fish made by an enzymatic and by a high-pressure acid treatment respectively were tested. The two preparations were similar in protein value and gave a growth response intermediate between that obtained with herring meal and with condensed herring solubles.

·INTRODUCTION

An increasing amount of the herring meal produced in British Columbia contains material that was formerly either lost in the discarded presswater or, if the presswater were reclaimed, was marketed separately as condensed herring solubles. The possibility was suggested that the herring reduction process might be altered to produce oil and a liquid preparation of the entire fish. Today's feed manufacturing plants are designed to handle the addition of liquids or semi-liquids, e.g. molasses, feeding oil, tallow, or condensed fish solubles, to mixed rations. Accordingly it was felt that if a "liquid fish" could be successfully prepared it might find wide acceptance provided it could be shown to be of high nutritive value.

MATERIALS AND METHODS

Two preparations of liquid fish were made by an enzymatic and high-pressure acid process respectively (McBride, Idler and MacLeod, 1961). The nutritive value of the liquid fish was compared with that of commercial British

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Columbia samples of condensed herring solubles, presscake herring meal and whole (i.e. presscake plus solubles) herring meal in chick tests. The chemical compositions of the materials tested are given in Table I.

TABLE I. Proximate analysis of various herring supplements used in the chick rations.

Supplement	Solids	Protein	Oil	Ash	pH
	%	%	%	%	
Enzyme-treated liquid fish	35.0	22.1	5.6	6.8	4.00
Pressure (acid)-cooked liquid fish	43.0	32.9	1.9	8.2	4.82
Commercial condensed herring solubles	47.2	35.2	3.9	8.4	4.10
Presscake herring meal	92.3	74.0	8.9	9.1	–
Whole herring meal	92.1	74.5	9.4	8.3	–

The formula of the basal diet with which the different products were fed was as follows: dextrose 16.0, ground yellow corn 76.0, dehydrated cereal grass 2.5, distillers dried solubles 2.0, iodized salt 0.5, bonemeal 2.0, limestone 1.0, and manganese sulphate 0.014 lb per 100 lb; vitamin A 2000 I.U. and vitamin D_2 120 I.C.U. per lb. This basal mixture contained 8.2% protein (% nitrogen × 6.25). Each of the products to be tested was added to supply 3% of protein in the total diet. A mixture of isolated soybean protein and amino acids in the following proportions was employed as a reference protein: isolated soybean protein (91% protein) 100, dl-methionine 2, glycine 3, and lysine hydrochloride 3.5.

The chicks used were White Leghorn cockerels. They were fed the basal diet without supplementary protein for 2 weeks. At 2 weeks the population was reduced by eliminating the slowest and the most rapidly growing chicks. Eighteen standardized lots of 15 chicks each were made up and each diet was fed to triplicate lots for 20 days.

RESULTS

FLUCTUATION IN THE TEMPERATURES OF THE PREPARED CHICK DIETS

The diet containing the enzyme-treated liquid fish heated considerably and reached a temperature of 43 to 44°C during the third week after mixing. Subsequently the temperature dropped. The diet containing the liquid fish prepared by acid treatment showed no evidence of fermentation until the 23rd day and had heated to 33°C at the time the experiment was completed. The highest temperature noted in the reference diet was 22°C.

CHANGES IN THE WEIGHT GAIN OF THE CHICKS

The growth responses of the chicks to the different preparations as protein supplements are shown graphically in Fig. 1. The average weights of the birds
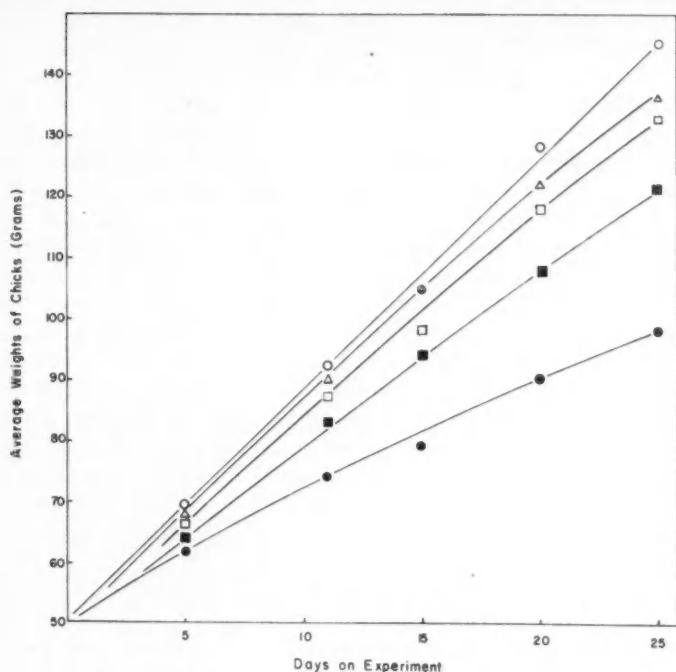
FIG. 1.   Growth response of chicks to herring product supplements.
○ Presscake meal.   △ Whole meal.   □ Reference protein.   ■ Liquid fish
(acid-treated and enzyme-treated).   ● Condensed solubles.

after 20 days on the experimental diets and the efficiency of feed utilization to
this time are given in Table II.   Mortality during the last 5 days of the experi-
ment made calculations of the feed efficiency for this period meaningless.

TABLE II. Average weights of chicks and efficiency of feed utilization
at 20 days of age.

Supplement	Average weight	Feed efficiency (feed/gain)
	grams	
Reference protein	118	3.74
Enzyme-treated liquid fish	108	3.76
Pressure (acid)-cooked liquid fish	108	3.73
Condensed herring solubles	90	4.72
Presscake herring meal	128	3.46
Whole herring meal	122	3.44

DISCUSSION

The ratio of gain of chicks fed the two types of liquid fish were similar and intermediate between the growth rates of the chicks fed meal and condensed solubles respectively. Unfortunately, as a result of the fermentation in the diet containing the enzyme preparation it is not known if this preparation might have given a better growth response had fermentation not occurred.

The condensed herring solubles allowed a relatively poor rate of growth as would be anticipated from the amino-acid balance of the protein going into the presswater in the reduction process (Almquist, 1949; Ney et al., 1950). Carpenter and Ellinger (1955) obtained a gross protein value of 67 for condensed herring solubles as compared to values of 93 and 98 for samples of herring meal. Laksesvela (1958) likewise has reported that condensed herring solubles is of negligible value as the sole source of protein in a chick diet. Laksesvela found, however, that certain mixtures of herring solubles and herring meal were superior to meal alone. Sure and Easterling (1952) found the net utilization value of the protein from a sample of herring meal with solubles to be 73.6 as compared with a value of 69.5 for a sample of ordinary herring meal. In the present experiment there was no significant difference between the average weights of the chicks fed the presscake meal and those fed the whole meal.

The differences in the efficiency with which the diets were utilized reflected the differences in the growth response to the various supplements. The condensed herring solubles resulted in the poorest feed efficiency, the two samples of herring meal promoted high feed efficiency and the two liquid fish preparations gave intermediate values.

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Scale to Length Ratio, Age and Growth of Atlantic Salmon in Miramichi Fisheries[1]

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ABSTRACT

The following quadratic equation relating fork length to scale radius is derived for Atlantic salmon taken in the Miramichi commercial fisheries:

$$L = 2.40 + 12.90S + 1.22S^2$$

where L = fork length in cm; and S = anterior scale radius in mm. The value 2.40 represents the fork length in cm of the fish when the scales first appear. Smolt transformation occurs after the young have reached an approximately similar size (about 12 cm) regardless of age. Five-year-old fish with 3 river years and 2 sea years predominate in the catch. Repeat spawners constitute only about 1/20 of the catch of salmon larger than grilse.

INTRODUCTION AND ACKNOWLEDGMENTS

THIS REPORT comprises an analysis of material gathered from Atlantic salmon (*Salmo salar*) taken in the commercial fishery in the vicinity of the Miramichi River, New Brunswick, during the month of June 1929. These Miramichi samples are also compared, for size and growth rate, with samples from the Grand Cascapedia River (Calderwood, 1928) and the Moisie River (Menzies, 1926) (Fig. 1).

It gives me pleasure to acknowledge the encouragement and assistance of Dr A. G. Huntsman, who was at that time Director of the Atlantic Biological Station, St. Andrews, N.B., of the then Biological Board of Canada, and under whose direction this work was done. I also wish to thank Messrs Frank and Robert Loggie of the A. and R. Loggie Co. of Loggieville, and Mr McInerney for assistance in obtaining the material.

I wish to acknowledge the contribution made by Dr P. F. Elson of the Fisheries Research Board's Biological Station at St. Andrews, N.B. His careful review of the paper and the addition of some of his recent findings have greatly strengthened the presentation.

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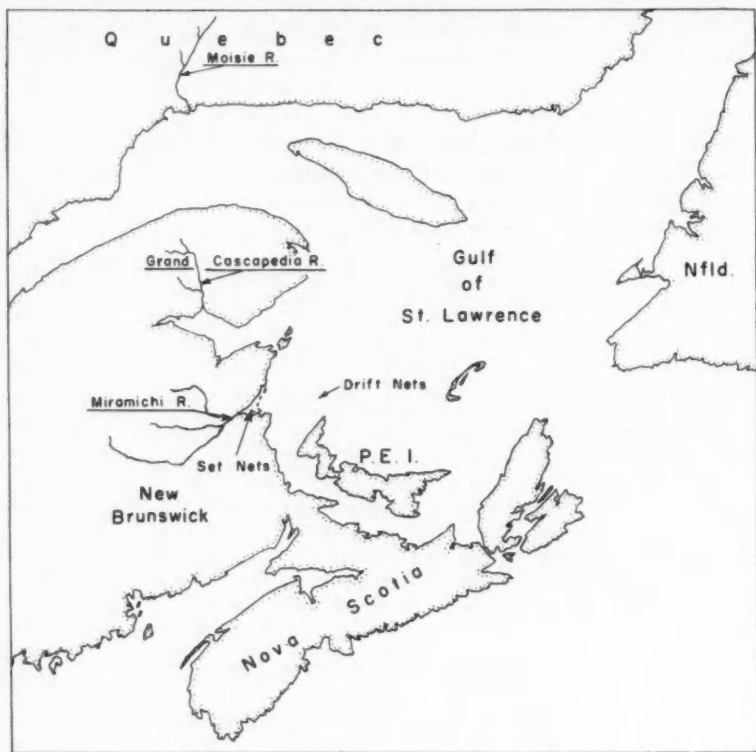
FIG. 1.   The Gulf of St. Lawrence and adjoining land areas, showing three important salmon rivers, the Miramichi, the Grand Cascapedia and the Moisie.   The approximate areas of the Miramichi commercial fisheries are also indicated.

MATERIAL AND METHODS

The lengths (to the fork of the tail) and weights of 436 salmon were recorded. For each of these fish about 40 scales were removed from an area just behind the dorsal fin and between the lateral line and the dorsal margin of the fish.

The scales were examined and the following facts determined: the total age of the fish, the smolt age, and the presence or absence of a spawning mark. Measurements, using a graduated micrometer disc in a microscope, were also made on 3 scales from each virgin fish to determine the final length of the anterior radius and the same radius at the end of each winter's growth.

From these measurements the length of the fish at the end of each winter's growth was determined according to the method described by Huntsman (1918).

RESULTS

SCALE LENGTHS AND FISH LENGTHS

To obtain the relationship between the scale radius and the fish length the average scale radius of 10 fish of each of several lengths was determined. The data concerning young fish was obtained from stock reared at the Miramichi hatchery. These values were plotted in a graph (Fig. 2). The relationship between the scale radius and the fork length of the salmon is parabolic and is expressed by the equation:

$$L = 2.40 + 12.90S + 1.22S^2$$

where L = fork length in cm; and S = anterior scale radius in mm.

The intercept of this curve on the L-axis at 2.40 cm nominally represents the length of the fish when the scales first appear. In point of fact, development of the scale-covering over the body of fish appears to spread progressively from primary centres of origin located along the lateral line as described for speckled trout (*Salvelinus fontinalis*) by Elson (1939). Elson found that in speckled trout
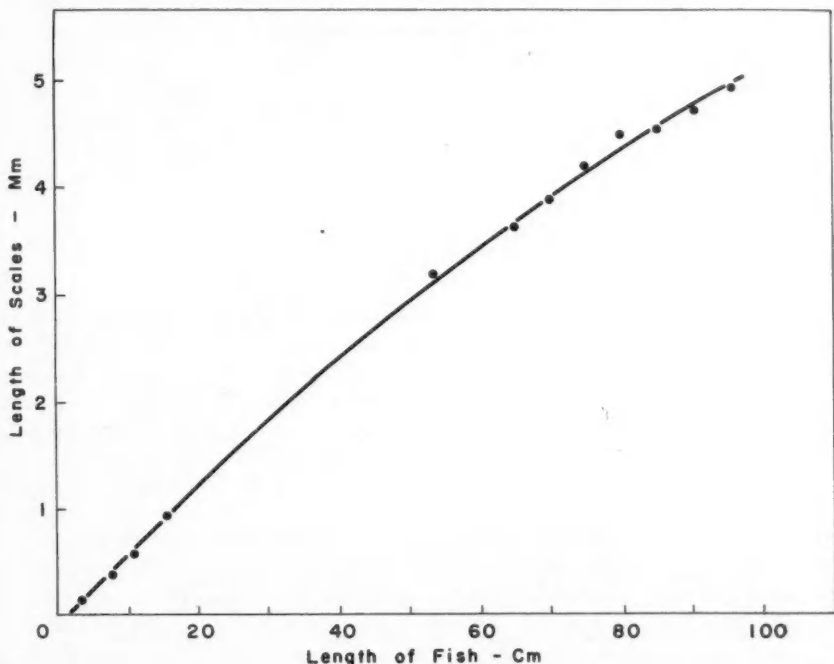

FIG. 2. The observed relationship between length of anterior scale radius (S) and fork length (L) of Atlantic salmon, as found for 436 fish taken in the Miramichi commercial fisheries in June 1929. The parabolic curve is described by the equation $L = 2.40 + 12.90S + 1.22S^2$.

the process was started at a total length (to midway between tips of tail fin when extended naturally) of about 3.0 cm and completed when the fish reached about 6.0 cm. He finds (personal communication) that for salmon the general order of scale appearance is similar to that for trout, but scale development occurs while the fish are growing from about 2.5 to 4.0 cm. He concludes that application of a correction term such as that (2.40 cm) appearing in the above equation would be a useful device for computing fish lengths from scale measurements.

In the case of the herring Sherriff (1922) found that a parabolic relationship exists between scale length and fish length (to midway between tips of tail fin when extended naturally).

Age Classes

The commercial salmon fisheries carried on in the Miramichi area may be divided into two classes, that done by means of set nets within the estuary of the river and that done with drift nets outside of the estuary. Some interesting facts are revealed by an analysis of the age classes of maturing virgin fish from these two sources. Grilse (fish maturing at 1+ sea years) are not included in this analysis because no quantitative conclusions may be drawn from the number of grilse in the collection; the nets were of too large a mesh to capture the grilse in the same proportion as they took the larger salmon.

TABLE I Sea ages of salmon taken by set nets within the Miramichi estuary and drift nets in the adjacent open sea.

| Type of fishery | Winters in sea after migration as smolts | | | |
| | 2 | | 3 | |
	no.	%	no.	%
Set nets	208	100	0	0
Drift nets	160	85.5	27	14.5

No unspawned fish which had remained 3 years in the sea were caught within the mouth of the river, whereas 14.5% of the fish which were caught outside of the mouth of the river were fish which had remained 3 years in the sea before returning to the river. This may be explained in two ways: either the fish which have been in the sea for 3 years were not ready to ascend the river in June, or they were on their way to another river and were not going up the Miramichi River.

The lengths and weights of the various classes are given in Table II.

TABLE II. Smolt age and size of salmon taken in Miramichi commercial fisheries, June 1929.

| Smolt age | 2 sea winters | | | | 3 sea winters | | | |
| | Length | | Weight | | Length | | Weight | |
years	cm	in	kg	lb	cm	in	kg	lb
2	73.1	18.6	4.4	9.7	91.2	23.2	9.4	20.8
3	73.0	18.5	4.4	9.7	92.8	23.6	9.1	20.1
4	74.3	18.9	4.6	10.2	93.3	23.7	8.2	18.1

Table II suggests slightly greater length and weight when caught in the case of the fish which had stayed longer in the river as parr.   There is a similar correlation in the case of the lengths of the 3-sea-winter class, but the correlation is inverse for the weights of the 3-sea-winter class; however the numbers in the 3-sea-winter class were comparatively small (Table I).

Compared with the 1926 catch in the Grand Cascapedia River (Calderwood, 1928), these Miramichi salmon were about 1 to 2 kg (2–5 lb) less in weight and about 5 cm (2 in) shorter in length, for each age group.   Compared with the 1922 and 1923 catches in the Moisie River (Menzies, 1926), the Miramichi salmon were about 0.2 to 1.33 kg (0.5–3 lb) less in weight, and about 2 to 4 cm (0.8–1.6 in) shorter.

The grilse, as stated above, were not treated quantitatively.   However for 15 specimens it was determined that all had spent 3 years in the river and 1+ years in the sea.   The average length was 53.1 cm (20.9 in) and the average weight was 1.6 kg (3.5 lb).

SMOLT AGES AND LENGTHS

Smolt ages were determined for this collection of Miramichi salmon and compared with fish from the Grand Cascapedia and Moisie Rivers.

Compared with the Moisie and Grand Cascapedia fish (Table III), 3-winter smolts are more predominant in the Miramichi than in either of the other two rivers, 2-winter smolts are greater in proportion than in the Grand Cascapedia River but less than in the Moisie, and 4-winter smolts are less than in either of the other two streams.

TABLE III. Smolt ages of salmon (2 sea winters or more) caught in Miramichi commercial fisheries (June 1929), and by angling in the Grand Cascapedia (1926) and Moisie (1922 and 1923) Rivers, as percentages of total samples.

	Winters in river					Number of fish
	1	2	3	4	5	
	%	%	%	%	%	no.
Miramichi	0	19.3	78.2	2.5	0	436
Grand Cascapedia	0	6.0	58.8	34.1	1.1	182
Moisie	0	56.0	39.0	4.7	0.3	377

These Miramichi area salmon differ markedly from those in Scottish rivers in that there are no 1-winter smolts in this sample; this difference has also been pointed out by Calderwood (1928) in the case of the Grand Cascapedia salmon.

The lengths of the smolts at migration and the lengths of the parr before migration were calculated as described above.   The average lengths are tabulated in Table IV.

The 2-winter length is 1.5 cm greater than that for the Moisie River; the 3-winter length similar and the 4-winter length 2 cm less; in comparison with

TABLE IV. Average fork lengths, at earlier stages of their life, of virgin salmon (2 sea winters or more) taken in the Miramichi commercial fisheries in June 1929, as calculated from scales removed at capture. Calculations were made according to the formula $L = 2.4 + 12.90S + 1.22S^2$, where L = fork length of fish in cm, and S = anterior scale radius in mm.

Smolt age	Length at end of winters					
	In the river				In the sea	
	1	2	3	4	1	2
years	cm	cm	cm	cm	cm	cm
2	5.9	11.5	. . .	. . .	45.4	66.9
3	5.2	8.6	12.0	. . .	44.6	71.4
4	4.7	7.5	9.9	12.9	45.5	66.9

those of the Grand Cascapedia River, the 2-winter smolts are very nearly the same length, while the 3- and 4-winter smolts are 1.5 to 2 cm less.

As shown in Table IV, fish which migrate at 2 years (2 winters) of age are longer at that age than those fish which do not migrate until they are 3 or 4 years of age; also the fish which migrate at 3 years of age are longer at that age than those fish which do not migrate until they are 4 years of age. In fact, these fish conform well with the hypothesis advanced by Elson (1957) that, in order to become smolts in the following spring, young salmon parr must reach a total length of at least 10 cm during the preceding season of growth.

CALCULATED LENGTHS AFTER MIGRATION

The lengths of the fish at the end of each winter after migration were also calculated and are included in Table IV.

Compared with the actual measurements at capture of grilse and of 2-sea-year salmon (Table II), these calculated lengths are slightly less. This is at least partly attributable to the fact that many of the fish showed, by their scales, that some growth had taken place between the end of the last winter in the sea and the time of capture.

SPAWNED FISH

In this collection there were 25 fish (5.7% of the sample) which had spawned previously. Of these fish 24 had spawned once previously and one had spawned three times previously.

The fish which had spawned once may be divided into two classes. The first class consists of those fish which had spawned first as grilse and then spent another year in the sea. These were 12 in number (2.8% of the sample); they averaged 75.5 cm (29.7 in) in length and 4.8 kg (10.6 lb) in weight. The other class consists of those which had spawned first as 2-sea-year salmon, then spent another year in the sea; these also were 12 in number, but averaged 90.5 cm (35.6 in) in length and 8.5 kg (18.6 lb) in weight.

No fish which had previously spawned twice were recorded.

The one fish which had spawned three times measured 119 cm (46.9 in) and weighed 19.1 kg (42 lb). Its scale record showed that it had been a 3-winter smolt, spawned first as a 2-sea-year salmon and thereafter in alternate years— so that it was returning in its 12th year of life (age 11+).

RATE OF GROWTH

The rate of growth, to the end of the second winter at sea, is considered separately for each smolt-age group. Calculated lengths at the end of each year, for each smolt age, can be seen by inspection of Table IV, and in Fig. 3. The growth in the river is represented by that part of the curve which has a relatively
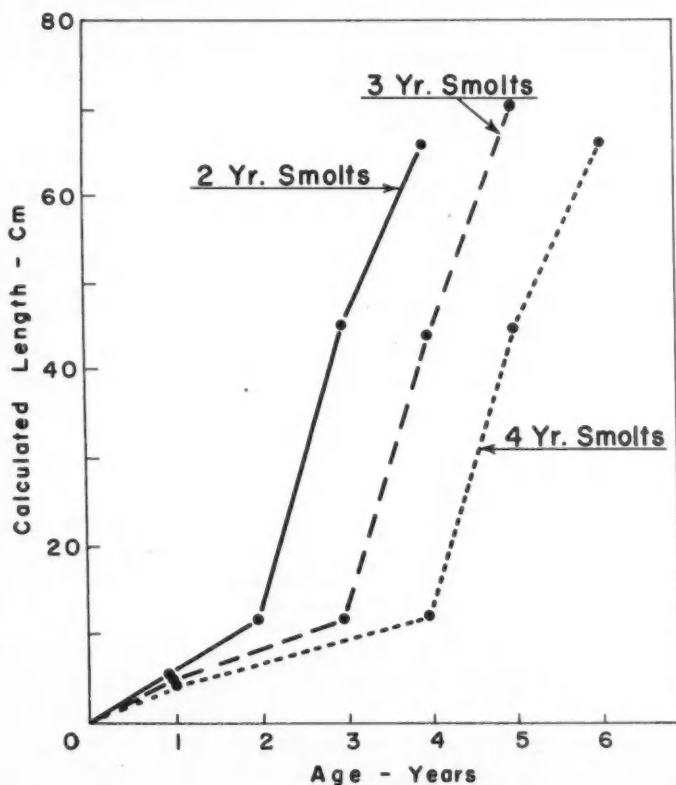

FIG. 3. Growth rates of Atlantic salmon taken in Miramichi commercial fisheries in June 1929, as calculated from scale measurements. The curves are extended only to the end of the second winter at sea, not to final length at capture which would be a little longer for 2-sea-winter fish and much longer for 3-sea-winter fish.

gradual slope, whereas the growth in the sea is represented by that part of the curve with the much steeper slope.   The great difference in rate of growth in the river and in the sea is shown clearly.   In each smolt-age group the increment of length added during the second year after migration is less than that added during the first year.   But the rates of growth in the sea are similar for all three smolt-age groups.

SUMMARY

1. Scales of 436 salmon from the Miramichi commercial fisheries were examined and the age and other particulars were determined.

2. The anterior scale radius (S in mm) is related to the fork length (L in cm) of these Atlantic salmon by a parabolic relationship of the form $L = 2.4 + 12.90S + 1.22S^2$.   The value 2.4 is a correction term which compensates for the fact that scales only begin to appear after the fish reaches a length of about 2.5 cm.

3. The predominating smolt age of these salmon was 3 years.

4. Almost 95% of this sample from the Miramichi salmon fisheries consisted of virgin fish which had spent 3 years in the river and 2 years in the sea.

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Liver Glycogen Reserves of Interacting Resident and Introduced Trout Populations[1]

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ABSTRACT

Three groups of trout, two introduced populations of *Salmo gairdneri* and a resident *Salmo clarki*, were studied in stream sections. Liver glycogen deposits, which were reduced to low levels during transportation to the stream, were restored in 2 to 3 weeks in all groups, with recovery rates being approximately inverse to the population density. Within the hatchery groups, larger fish laid down greater glycogen stores. Wild trout maintained their high glycogen reserves throughout the experiment.

INTRODUCTION

RECENT INVESTIGATIONS in fish behaviour, such as those of Braddock (1949) indicating the relation between prior residence and dominance, as well as those of Newman (1956), stressing the relation between size and dominance, have led to physiological studies of trout interactions. Accordingly, Miller (1958), examining the lactic acid produced during competition between planted and resident stocks, showed that in a stream environment at least, prior residence and dominance are related. The size factor, however, has not been explained on such a basis.

Essentially a continuation of Miller's work, this study is an attempt to evaluate the responses of different-sized planted trout to interactions between themselves and resident fish. An analysis of liver glycogen stores suggests a chemical basis for the relation of size and prior residence to dominance.

THE TEST AREAS

South Gorge Creek, one of the test streams of the Alberta Biological Station, was selected for this study. Conditions were similar to those previously described by Miller (1958) for the main Gorge.

Indigenous *Salmo clarki* were confined in 3 experimental zones, each about 300 yards long, screened off by fish-proof fences. In zones 1 and 2, these fish were removed with a fish toxicant. On the basis of this poisoning, the population of the 3rd area was estimated to be about 60.

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Hatchery-reared *Salmo gairdneri* were then spot-planted into each zone.   Two groups, the same lots as those of Miller *et al.* (1959), were used.   In one lot, the fish had an average weight of 95.8 g and had been fed on Clark's dry rations (see Miller *et al.* for description), while in the second, fed on beef liver, the average weight was 65.6 g.   Both lots of fish were the same age.   The resident *S. clarki* were smaller than the fish in either hatchery group, averaging 52.8 g.

After planting, the experimental areas contained the following numbers of rainbow trout:

Section I   100 trout, 50 liver-fed and 50 Clark-fed

Section II   200 trout, 100 liver-fed and 100 Clark-fed

Section III   160 trout, 50 liver-fed and 50 Clark-fed plus 60 resident cut-throat trout.

Because of their small size, the experimental areas showed marked differences in their suitability for supporting trout populations.   Hence, it was desirable in this respect to compare the zones relative to one another.

Table I summarizes the descriptive data of the experimental areas.   Mean depth, width, and volumes of flow were very nearly the same, as were the values recorded for bottom fauna.

TABLE I. Description of experimental areas in South Gorge.

Section	Mean width	Mean depth	Length	Volume of flow	Bottom fauna Vol./sq ft	Organisms
	ft	*ft*	*ft*	*cu ft/sec*	*cc*	*no.*
I	14.0 (4–24)	0.75	1000	11.6	0.7	49
II	13.0 (4–24)	0.60	1000	9.5	1.0	44
III	13.0 (4–27)	0.85	1000	10.7	0.7	50

In Table II, pools and bank cover are compared.   Boussu's (1954) definition of a pool as a comparatively deep section with quiet surface waters, appreciable reduction in water velocity and with a bottom of silt or clay, was adopted.

TABLE II. Description of pools and bank cover. Length, depth and width were determined at 3 to 5 points in each pool.   Each grade of bank cover is expressed as a percentage of the total bank length, to the nearest 5%.   (1 yd = 3 ft = 0.9 m.)

Section	Pools Total area	Mean width	Mean length	Mean depth	Bank cover grade 1	2	3
	sq yd	*yd*	*yd*	*ft*			
I	150	4.4	9.2	1.0	50	20	30
II	236	5.8	11.6	0.9	30	20	50
III	360	5.8	13.5	1.0	45	35	20

Borderline cases were encountered, but since all the determinations were made by the author alone, the values are probably valid relative to one another.

A comparison of relative population densities could be made by simply expressing the population in each zone as numbers of fish per unit of pool area (Table III). Section 3 is the most favourable, Section 2, the least. To check this evaluation, an analysis of bank cover was made. On the south Gorge, bank types range from steep sloping banks of sheer shale or rock to ones of

TABLE III. Number of trout per 5 square yards (4.2 m²) of pool in the experimental zones.

Section	Number
I	3.3
II	4.2
III	1.5
Wild stock areas	1.0

overhanging dense stands of vegetation, frequently with undercut fertile edges. Hence, evaluation of cover in the 3 zones was possible only by arbitrarily establishing grades of bank types. These were defined as follows:

Grade I   Vegetation overhanging water, supplying food and cover.

Grade II   Bank vegetation separated from the water by only a short distance (up to 3 yards—2.7 m); or, no bank vegetation, but overhanging rocks, logs, etc., supplying good cover.

Grade III   No vegetation or other cover. Bank of rocks, boulders, shale and/or gravel.

Bank vegetation included:

Salix sp.	Vicia sp.	Anemone sp.
Populus tremuloides Michx.	Juncus sp.	Pyrola sp.
Populus balsamifera	Epilobium angustifolium L.	Ribea sp.
Picea glauca	Epilobium latifolium L.	Lonicera sp.
Picea mariana	Actaea rubra (Ait.) Willd.	Aster sp.
Juniperus horizontalis (Moench)	Heracleum lanatum Michx.	Senecio sp.
Pinus contorta Dougl.	Taraxacum sp.	Achilles sp.
Rosa sp.	Betula sp.	Equisetum sp.
Potentilla fruticosa L.	Campanula sp.	Shepherdia sp.
Fragaria sp.	Castilleja sp.	Elaeagnus sp.
Lathyrus sp.	Habenaria sp.	Deschampsia sp.
Hedysarum sp.	Carex sp.	

Table II shows that the test zones differed primarily in the amount of bank grades 1 and 3. Sections 1 and 3 were similar, both being superior to Section 2. This rating is in fair agreement with that based on total pool areas and suggests that fish would be expected to do better in Section 1 or 3 than in Section 2, while, because of density differences, Section 3 fish would be expected to do better than

those in Section 1.   This expectation is considered in evaluating the experimental results.

METHODS

Each fish was marked with a numbered Petersen tag in the Calgary Hatchery, about one week prior to planting.   During transportation from the hatchery, water was continually oxygenated, and the fish were maintained at low densities, to keep them in good condition.   The trout were carried to the stream in large 30-gallon cans and spot planted.   During the experiment the fish were recaptured either by angling or seining.

Liver examples were taken from a few fish of each lot on arrival at the experimental area.   After this, sampling was carried on at the end of the 1st, 2nd, 3rd and 4th weeks after planting.   Samples were placed directly into weighed capped test tubes containing 30% potassium hydroxide.   These were re-weighed at the laboratory and the dissolved tissues were analyzed for glycogen by the method of Montgomery (1957).   All trout used were killed within 30 seconds of capture by decerebration.   Tissue sampling was completed within about 60 seconds after capture.

Stomach samples were collected, weighed and compared relative to total body weights.

Stream descriptive data were collected upon completion of the experiment, i.e. in early September.   Plant identification, rendered difficult because of the time of the year, was based on Budd's key (1957).   Stream description was patterned after Lagler (1957).

RESULTS

DISTRIBUTION OF HATCHERY TROUT FOLLOWING PLANTING

Within 24 hours after planting, each trout group had dispersed throughout the experimental areas.   Trout were most conspicuous in Section 2 and in the pools very near to the downstream screens of each of the other sections.

In all zones, during the first few days, trout were frequently seen resting vulnerably in very shallow, slow moving waters.   Again the number visible was greater in Section 2 than in the other sections.

WEIGHT CHANGES AFTER PLANTING

Table IV summarizes the weight changes after planting, expressed as a percentage amount less than the weight at planting.   Differences between the diets were not large, though the smaller trout tended to lose relatively more weight in most areas.   Initial loss rates were much the same under all densities.   However, Section 3 trout under the lowest population density showed lower weight losses than both the other lots.   This was especially pronounced at 2 and 4 weeks after planting.   When the data are treated irrespective of diet, the Section 3 fish showed the lower weight loss consistently.

TABLE IV. Weight changes after planting, expressed as percentage decrease from planting weight.

Section	Lot	Days after planting			
		6–8	13–15	20–22	27–29
III	Clark-fed	16.4	15.3	19.0	15.2
	Liver-fed	16.4	19.5	21.2	16.9
	Average	16.4	17.4	20.1	16.1
I	Clark-fed	16.8	16.5	24.8	16.3
	Liver-fed	15.7	20.7	22.8	19.0
	Average	16.2	18.6	23.8	17.6
II	Clark-fed	15.6	18.1	23.1	21.1
	Liver-fed	18.7	23.1	23.4	24.2
	Average	17.1	20.6	23.3	22.7

THE STOMACH CONTENTS OF HATCHERY AND WILD TROUT

If stomach content can be used to indicate trout feeding, then Table V shows most clearly the superiority of the resident wild *S. clarki*. Within the hatchery groups, feeding increased gradually after planting. Large Clark-fed trout began feeding more actively than the liver-fed group within the first week

TABLE V. Weight of stomach contents, expressed as a percentage of body weight, for native *Salmo clarki* and planted *S. gairdneri*. (Numbers in brackets refer to number of stomachs examined.)

A. Wild *Salmo clarki*

	Days before planting			
	28	21	14	2
South Gorge Creek	1.10 (9)	2.59 (4)	1.51 (6)	1.07 (5)
	Days after planting			
	6–8	13–15	27–22	27–29
South Gorge Creek	1.03 (3)	0.94 (4)	1.00 (5)	0.81 (5)

B. Hatchery *Salmo gairdneri*

	Days after planting			
	6–8	13–15	20–22	27–29
SECTION I				
Clark-fed	0.12 (5)	0.07 (4)	0.13 (3)	0.18 (4)
Liver-fed	0.19 (5)	0.07 (4)	0.19 (3)	0.19 (4)
SECTION II				
Clark-fed	0.05 (5)	0.05 (3)	0.16 (5)	0.42 (5)
Liver-fed	0.02 (5)	0.07 (3)	0.21 (4)	0.46 (3)
SECTION III				
Clark-fed	0.24 (4)	0.34 (4)	0.28 (4)	0.63 (4)
Liver-fed	0.15 (4)	0.13 (4)	0.24 (4)	0.35 (4)

and this was maintained for the duration of the experiment. The trout subjected to the highest population densities showed slowest increase in ability to take in food.

Liver Glycogen Recovery after Planting

Data dealing with glycogen reserves in the liver of the planted trout are summarized in Table VI. Since no substantial variations were seen in the liver glycogen levels of wild *S. clarki* throughout the study period, their values were

TABLE VI. Liver glycogen of hatchery *Salmo gairdneri*, before and after planting, in grams per 100 g of tissue, with standard errors.

Lot	At planting	Days after planting			
		6–8	13–15	20–21	27–29
Clark-fed					
Section III	1.20 ± 0.17 (5)	2.40 ± 0.34 (4)	3.59 ± 0.34 (4)	3.50 ± 0.45 (4)	3.28 (4)
Section I	As above	2.01 ± 0.43 (5)	2.92 ± 0.07 (4)	3.31 (3)	3.17 (4)
Section II	As above	1.76 ± 0.15 (5)	2.16 ± 0.11 (3)	3.13 (4)	3.03 (5)
Combined	As above	. . .	. . .	3.32 ± 0.21 (11)	3.15 ± 0.20 (13)
Liver-fed					
Section III	0.60 ± 0.21 (5)	2.00 ± 0.35 (4)	2.73 ± 0.42 (4)	2.59 ± 0.46 (4)	2.67 (4)
Section I	As above	1.82 ± 1.9 (5)	1.75 ± 0.16 (4)	2.15 (3)	2.37 (4)
Section II	As above	1.26 ± 0.19	1.49 (4)	2.02 ± 0.12 (4)	2.90 (5)
Combined	As above	. . .	. . .	2.26 ± 0.18 (11)	2.65 ± 0.14 (13)

lumped into two categories, those before the onset of the experiment and those after: the pre-experiment average is 4.57 g/100 g tissue, with standard error of 0.38, based on 20 fish taken over 4 weeks; the average figure during the experiment is 4.41 ± 0.18, based on 19 fish.

The most striking fact arising from Table VI is that the wild trout liver glycogen levels are maintained above those of the planted rainbow trout throughout the entire period.

Perhaps the most significant difference between the experimental zones were the rates of recovery following planting. Clark's trout at lowest densities (Section 3) increased their liver glycogen reserves by about 200% within 2 weeks; those in Section 1, by about 160%; while Clark's trout in the densely populated Section 2 showed only about 75% increase in this time.

Liver-fed fish, probably because initial levels were somewhat lower, recovered at a rapid rate during the first week; those in Section 1 and 3 showing about 180%

increases, while the lot in Section 2 showed only 70% rises.   During the second week, the recovery rate was reduced.

In both liver- and Clark-fed trout at low densities, peak liver glycogen deposits were achieved a fortnight after planting.   The trout in the other two zones, however, irrespective of diet, did not show maximum deposition until the third week after planting.   This is most striking, especially in view of the fact that very large increases in liver glycogen can occur quickly with good feeding (Hochachka, unpublished).

Since liver glycogen levels were the same in all Clark-fed trout on arrival at the experimental areas (i.e. at planting), it is not surprising that differences betweeen trout planted in the different zones were not statistically different until a 2-week period elapsed.   At this time, deposits were significantly higher in trout living at lower densities (Section 1 and 3) than they were in those at high density.

By 3 weeks after planting, differences between the different density zones were again obliterated.   Since the trout were on the same natural diet, this was to be expected.   However, the liver glycogen levels of the hatchery trout at 3 and 4 weeks are significantly lower than those of the resident *S. clarki*.   Moreover, the *larger* Clark-fed fish had significantly higher levels than the liver-fed ones (at 3 weeks, P = 0.01, but by the 4th week this difference was reduced to the 0.05 probability level).

In sum, restoration of liver glycogen reached the maximum observed within 3 weeks.   After this time, *within each dietary lot*, glycogen stores remained the same, irrespective of population density.   However, larger hatchery trout achieved greater glycogen deposition than.smaller ones.   Wild trout in Section 3 maintained significantly higher reserves of liver glycogen than their hatchery counterparts, in spite of the fact that both were subjected to the same conditions.

Relations Between Trout Groups

Two approaches were used to obtain direct evidence for the presence of social orders; observations of activity within secluded stream portions, and feed-lot and/or size sequences in capture by angling.

Time sequences of capture within given pools indicated that feeding among the resident cutthroat trout was based largely on size, the larger fish being first to attempt to capture the food presented.   This generalization did not hold true in the mixed populations, where the smaller wild stock fed more actively than their hatchery counterparts.   Within the hatchery stocks, however, feeding was also related to size.

Except for several well-suited pools, observations of movements were difficult.   Those that were made can be summarized as follows: 1. Freedom of movement was greater among the resident trout.   2. Wild trout went to deep, dark, and well protected parts of the pools when inactive; hatchery trout swam

very close to the surface, often in shallow water. 3. Wild trout frequently molested introduced ones, but were seldom molested themselves. This behaviour of the wild trout is similar to the activity of the dominant trout in Newman's (1956) study.

DISCUSSION

WEIGHT LOSS AFTER PLANTING

Weight data are similar to those recorded in the literature. Miller (1951) reported about 20% losses in weight in 3-year-old planted trout, while 2-year-olds showed up to 65% decreases. In 1953, Miller noted that whereas 3-year-old pond-reared trout lost up to 20% of their weight at planting, stream-reared stock lost only 12% at maximum, and transplanted wild stock lost only 9%. Since the greatest drop in weight occurred during the first week or so, both in this and in Miller's studies, it is likely that starving was most serious during this time. Quick returns to normal weight ranges probably were postponed in favour of the utilization of energy from food intake for firmer establishment in the stream social structure.

Differences between diets were not apparent despite size differences, and the scatter between zones was so large that differences were not statistically valid. It is, therefore, concluded that weight changes can be used only as a crude index of the responses of fish to varying degrees of environmental stress.

LIVER GLYCOGEN

Liver glycogen levels are considered to be biochemical reflections of food intake, and as Fig. 1 shows, these vary approximately with the latter. This is further substantiated by Miller *et al.* (1959) as well as by data from the author's unpublished feeding experiments. Since these reserves quickly increase with food intake, and since all the trout were presumably taking the same type of food, dietary histories *per se* are assumed of little importance after the first week under natural conditions.

The smaller hatchery fish tended to have lower liver glycogen deposits for a given amount of food intake (see Fig. 1). This is probably spurious, for these energy deposits are highly labile, and are easily influenced by other factors, most notably, physical activity (Hochachka, unpublished; Miller *et al.*, 1959). It is probable that the lower glycogen deposition of the liver-fed trout is due to their stream position, which according to Miller (1958) would be inferior to that adopted by dominant fish.

It should be pointed out that the experimental hatchery trout were transferred for some 60 miles from the hatchery to the experimental stream. Liver glycogen levels at this time were about 20 to 25% of those normally seen, and differences between the diets were not significant.
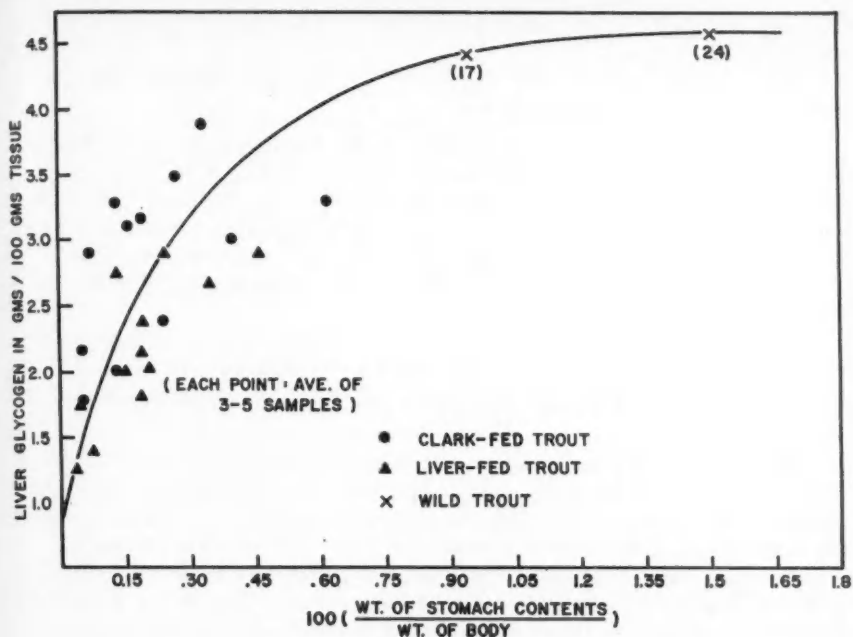
Fig. 1. Liver glycogen reserves per unit weight of tissue, plotted against stomach contents (as percentage of body weight), for all samples of planted *Salmo gairdneri* and wild *S. clarki*. The 24 wild fish are those taken prior to planting the hatchery trout; the 17 were taken after planting.

DOMINANCE-SUBORDINATION ORDERS

In his laboratory and field studies of trout behaviour, Newman (1956) found that rainbow trout portray a loose sort of rotating dominance-subordination relation in which "nip-right" and reciprocal aggressiveness prevail. Agressiveness became more severe during feeding, and if the subordinate fish were subjected to intense domination, they frequently failed to feed at all. This is especially important to a behaviour interpretation in this study, because of the direct relation between food intake and liver glycogen stores. Stringer and Hoar (1955) recorded two predominant patterns of behaviour in the trout social structure— chasing and nipping, with territorial defence, threatening, and fighting being associated with nipping. In both studies, the hierarchy was usually based on size.

If the trout groups in this study are arranged in order of merit on basis of liver glycogen stores, stream position, feeding, and other activity, the following sequence arises: wild stock > Clark-fed > liver-fed. The *size* sequence, of course, was: Clark-fed > liver-fed > wild stock. That is, all the evidence points to *wild-stock dominance despite size disadvantage.* Mortality data (Miller, 1958; unpublished data from this study), Phillips' *et al.* (1957) chemical data, as well as

unpublished results in the present writer's study of fish performance also support the above implication.

This contradiction of the size factor in dominance-subordination orders probably has two contributing factors:

(a) *Prior residence*. The importance of this factor has been experimentally demonstrated by Braddock (1949) and Miller (1958). The former showed that prior residence actually competes with the size factor in determining dominance, while the latter indicated the especial significance of prior residence in hatchery fish survival, as well as certain biochemical consequences. In this study, prior residence was, for at least 4 weeks, more important than size in determining dominance.

(b) The second factor could be a *less healthy condition of the larger hatchery fish*. Evidence for this is seen in the glycogen levels recorded as well as in Miller's lactic acid data. It is some such condition that Miller suggested as instrumental in delayed mortality.

Newman (1956), too, held that where dominance was acquired by smaller trout, it was due to the body state of the larger protagonist, and this worker recognized the other possible alternative as well, viz., that the smaller fish were more aggressive. The latter alternative could not be assessed in this study.

Finally, greater activity of dominant fish points to one of the rewards of dominance; selection of territory within a home range. (See Miller, 1954, 1957, for a discussion of trout home ranges). But increased activity also implies that the position of advantage is frequently relinquished, thus giving rise to Newman's rotating social structure. In essence, this is a sharing of the desirable position and is undoubtedly of value to the social group as a whole.

SUMMARY

1. The body weight changes and feeding activity of hatchery-reared rainbow-trout following stream planting were roughly related to the population density to which the fish were subjected.

2. Restoration of liver glycogen after planting reached the maximum observed within 2 to 3 weeks. After this time, within each dietary group, these stores were the same, irrespective of population density, but higher levels were obtained by larger trout.

3. Wild cutthroat trout, despite a size disadvantage, maintained higher liver glycogen reserves than did hatchery fish.

4. Liver glycogen depots were reduced to very low levels during transportation to the stream. At planting, the levels were the same in both dietary lots.

5. Interpreted on the basis of known patterns of behaviour, the small wild trout were dominant to the larger hatchery ones. This size discrepancy was probably due to a less healthy state of the hatchery fish and/or to the prior residence of the wild stock.

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Slicing of Fillets as an Aid in Detection and Removal of Codworms from Atlantic Cod Fillets[1]

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ABSTRACT

Slicing cod fillets longitudinally into slices ½ inch (13 mm) thick can increase the efficiency of candling cod fillets for codworms to over 95%. The increase is greater in the larger fillets than in the smaller fillets if sliced. If fillets are not sliced the candling efficiency decreases with increasing size of fillets.

INTRODUCTION

DETECTION OF CODWORMS (*Porrocaecum decipiens*) in fillets is very difficult when they are further than ¼ inch below the surface of the fillet (Power, 1957). In an attempt to improve methods of detecting these parasites for the purpose of removing them, experiments were conducted to determine the effect on the efficiency of candling the fillets, after slicing them longitudinally, parallel to the skin surface, into layers with a maximum thickness of ½ inch (13 mm) as shown in Fig. 1. The slicing was effected by means of a slicing machine designed by the
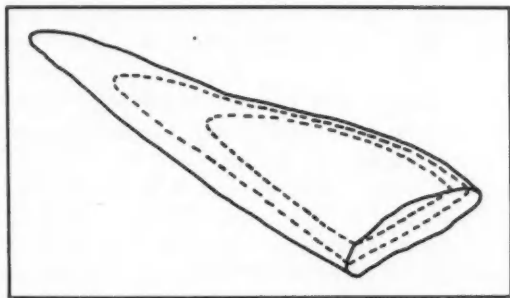

FIG. 1. Typical cuts made when a cod fillet is sliced for candling.

author at this Station (Power and Fougère, 1960). The machine employed four band knives crossed to form a figure "8", running on the same two pulleys. The blades were spaced ½ inch apart by means of steel guides. Fillets were fed to the blades by a conveyor belt. For these experiments heavily infested cod fillets were used.

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Table I shows the results of slicing and candling 228 heavily infested cod fillets.   First both sides of these fillets were candled under conditions similar to those under which fillets are candled commercially and the number of parasites was recorded.   The fillets were then cut into slices $\frac{1}{2}$ inch thick and again both sides were candled and the number of additional parasites found was recorded.

TABLE I.   Results of candling, slicing and again candling 228 cod fillets.

Size of fillet	Number of samples	Parasites found *before* slicing		Additional parasites found *after* slicing	
		Range	Av. per fillet	Range	Av. per fillet
Large	27	0– 2	0.223	0–12	1.26
Medium large	59	0–14	2.2	0–10	1.40
Medium	81	0– 8	1.04	0– 6	0.51
Small	61	0–18	2.54	0–11	0.156

Total number of fillets 228
Number of fillets containing parasites 153 (67%)
Total number of parasites removed 644
Number of parasites found before slicing 375 (58%)
Number of worms found after slicing 269 (42%)
Average number of worms per fillet 2.82

Table I shows that of the 644 parasites removed from the fillets, 269 (42%) were removed after slicing, having been invisible during normal candling.   The percentage of infested fillets in this group (67%) is considerably higher than the mean percentage of infested fillets from fish taken from the banks off the south coast of Nova Scotia.   Scott and Martin (1957) report that 5 to 24% of such fish are infested.

To determine the effect of fillet size on the efficiency of candling sliced cod fillets, three batches of fillets were candled under commercial candling conditions, identical to those under which the fillets referred to in Table I were candled. Forty pounds of small fillets (average weight 0.55 lb), 40 lb of medium fillets (average weight 0.77 lb), and 40 lb of large fillets (average weight 1.14 lb) were candled and the numbers of parasites removed were recorded.   These fillets were then sliced into layers as shown in Fig. 1 and the additional parasites removed were recorded.   After the second candling, the fillets were shredded by hand to determine the number of parasites which had remained undetected.

Candling efficiency may be stated by the expression:

$$\frac{\text{Number of parasites detected by candling} \times 100}{\text{Total number of parasites}}$$

The candling efficiency for these small, medium, and large fillets is shown in Table II.   For small fillets the candling efficiency is shown to increase from 26.9 to 95.4% by slicing the fillet.   Residual worms were 4.6% of the total or 20 per 100 lb of fillets.   For medium-size fillets the candling efficiency increases

TABLE II. Results of candling, slicing and again candling 40 lb of three typical sizes of cod fillets.

	Small	Medium	Large
Number of fillets	73	52	35
Average weight of fillets (pounds)	0.55	0.77	1.14
Range of parasites found in fillets before slicing	0– 4	0–14	0– 9
Range of parasites found in fillets after slicing	0–15	0–38	0–34
Range of residual parasites	0– 2	0– 1	0– 2
Total number of parasites found in fillets	175	223	306
Number of parasites found before slicing	47 (26.9%)	54 (24.2%)	68 (22.2%)
Number of additional parasites found after slicing	120 (68.5%)	163 (73.1%)	231 (75.5%)
Total number of parasites after slicing	167 (95.4%)	217 (97.3%)	299 (97.7%)
Number of residual parasites available	8 (4.6%)	6 (2.7%)	7 (2.3%)
Total parasites per 100 lb fillets	438	560	765
Residual parasites per 100 lb fillets	20	15	17.5
Candling efficiency before slicing =	$\frac{47 \times 100}{175}$ $= 26.9\%$	$\frac{54 \times 100}{223}$ $= 24.2\%$	$\frac{68 \times 100}{306}$ $= 22.2\%$
Candling efficiency after slicing =	$\frac{167 \times 100}{175}$ $= 95.4\%$	$\frac{217 \times 100}{223}$ $= 97.3\%$	$\frac{299 \times 100}{306}$ $= 97.7\%$

from 24.2 to 97.3% when the fillet is sliced, with residual worms 2.7% of the total of 15 per 100 lb of fillets. The candling efficiency for large fillets increases from 22.2 to 97.8% when candled after slicing. The percentage of residual worms in this case was 2.3% of the total or 17.5 per 100 lb of fillets.

In Fig. 2 the candling efficiency has been plotted against weight of fillets
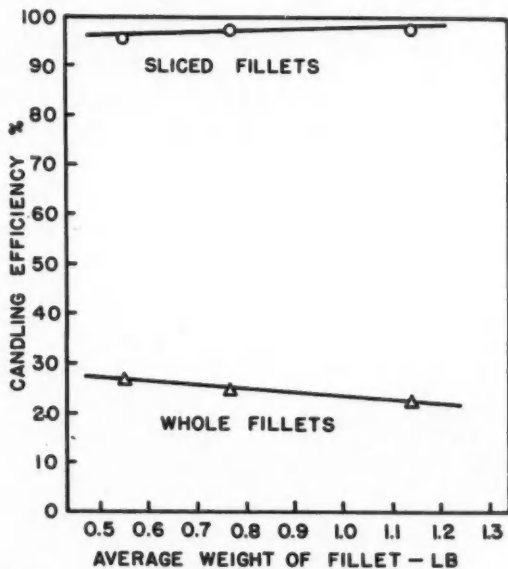

FIG. 2. Curve showing variation in candling efficiency
with size of sliced and unsliced fillets.

for unsliced fillets and for sliced fillets.   As can be seen the candling efficiency for sliced fillets is much greater than that for whole or unsliced fillets and tends to increase as the size and thickness of the fillet increases.   With unsliced fillets the candling efficiency tends to decrease with increase in size of fillet.

A small number of parasites, less than 5%, will not be detected even if the fillets are sliced before candling, being hidden in the brown-coloured flesh of the fillet, or under the silver bloom which remains on part of the fillet after skinning. However, it is believed that they are harmless to man and this belief is borne out by the results obtained by feeding *Porrocaecum* to beagle pups as part of their diet (Crampton *et al.*, 1960).

SUMMARY

When heavily infested cod fillets are candled under commercial conditions for parasites, it can be expected that only a quarter of the total number of parasites will be found and removed.   However, if the fillets are cut into slices $\frac{1}{2}$ inch thick and candled, it can be expected that over 95% of the parasites will be found.

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NOTES

Northward Range Extension of the Flathead Chub
and Trout-perch to Aklavik, N.W.T.

Seine hauls in the Peel Channel of the Mackenzie River delta at Aklavik (68° 13.5′ N Lat., 135° 00′ W Long.), Northwest Territories, Canada, produced two species north of their recorded range, the flathead chub (*Platygobio gracilis*) and the trout-perch (*Percopsis omiscomaycus*). The northernmost record in the Mackenzie system for these species was at Fort Good Hope in the Mackenzie River, more than 200 miles southeast of Aklavik by air (V. C. Wynne-Edwards, *Bull. Fish. Res. Bd. Canada*, No. 94, 1952). The trout-perch has also been collected closer to Aklavik but in the Yukon River system, at Old Crow, Porcupine River, 67° 40′ N Lat. (Wynne-Edwards).

Accompanying these two species in the seine hauls were the lake chub (*Couesius plumbeus*) and the spoonhead sculpin (*Cottus ricei*), both recorded only once without definite locality from the delta, and also the longnose sucker (*Catostomus catostomus*) and several young coregonids. These fish are catalogued as NMC60–455 in the fish collection of the National Museum of Canada. The fish were seined in muddy water, 0–1.5 feet deep, 13.0° C, mud bottom on July 12, 1960, by the author and J. Bray of the Fisheries Research Board, while the former was associated with the Board's 1960 program of the M.V. *Salvelinus*.

Temperature would not appear to greatly limit northward distribution in the Mackenzie since it brings warm water north from southern regions, and winter temperatures descend no lower near its mouth than near its source. Hence these and other species might be expected to extend to within tidal influence at the mouth of the Mackenzie.

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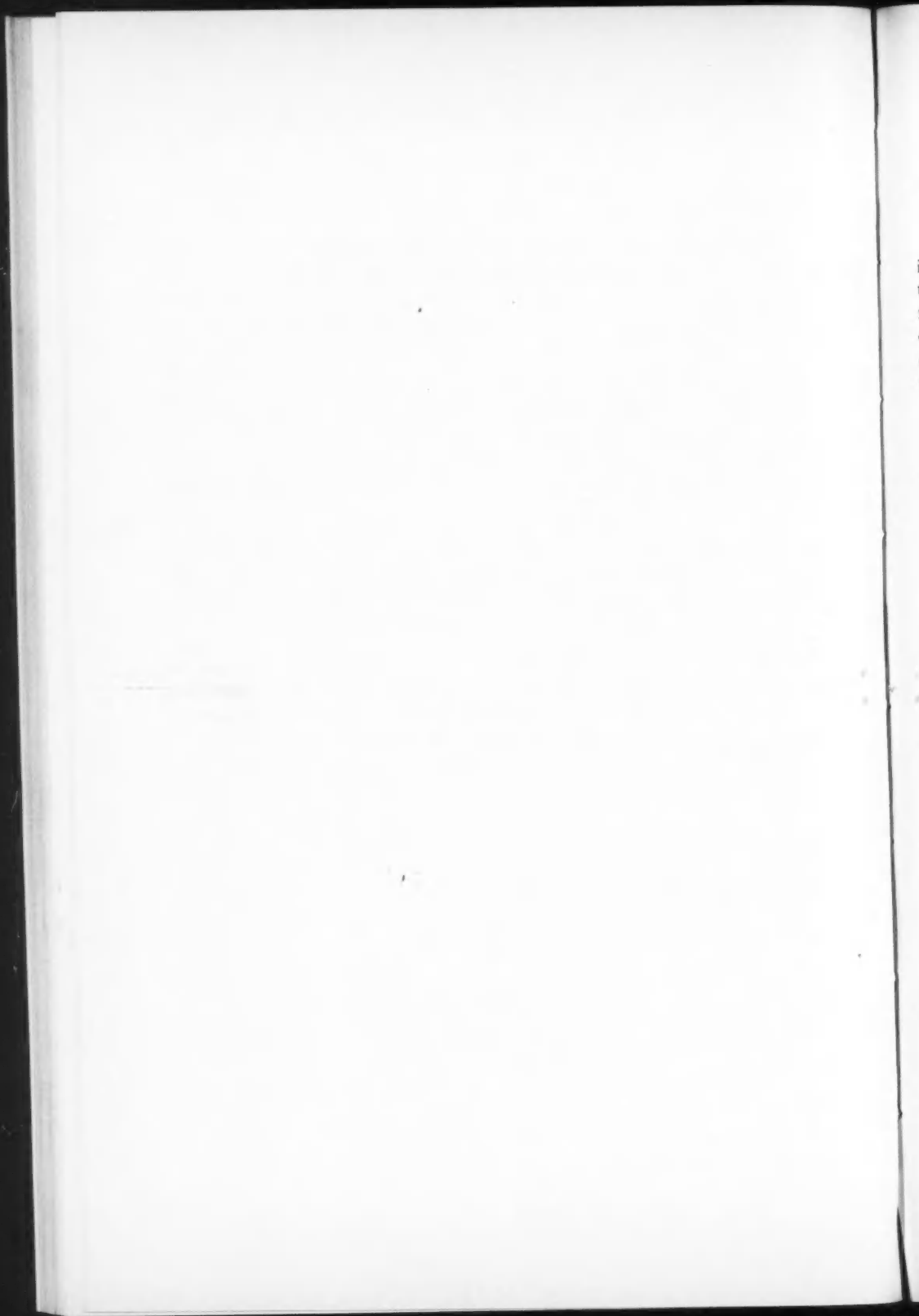
Lipid Hydrolysis in Frozen Cod Muscle[1]

Protein denaturation in frozen cod muscle is accompanied by a marked increase in the free fatty acid content of the tissue and it has been suggested that the two processes may be related (Dyer and Fraser, 1959). This communication is a preliminary report of studies undertaken to establish the identity of the precursors of the liberated fatty acids. The work is part of a program designed to elucidate a possible relation between lipid hydrolysis and protein denaturation in frozen fish muscle.

In stored frozen cod, the free fatty acid content often amounts to more than 50% of the total extracted lipid (Dyer and Fraser, 1959). Garcia *et al.* (1956) found that cod muscle lipid contained 50 to 65% phospholipid whereas only 3% was triglyceride. The other fatty-acid-containing constituents, cholesterol esters and "unidentified lipids", corresponded to 5 and 21% of the total lipid respectively. Therefore, phospholipid hydrolysis must be responsible for at least part of the increase in free fatty acid. Furthermore, Cardin and Bordeleau (1957) and Cardin *et al.* (1958) found that phospholipids were hydrolysed during the preparation of salt cod, and recently Lovern *et al.* (1959) reported the same occurrence when cod was kept in ice for prolonged periods. However, Tomlinson *et al.* (1960) did not observe statistically significant phospholipid breakdown in lingcod muscle held for a comparatively short time at 0°C. Olley and Lovern (1960) have concluded that phospholipid hydrolysis in cod flesh stored at various temperatures was due to tissue enzymes.

Preliminary analyses of the lipids from fresh cod and from various samples of stored frozen cod showed that the free fatty acid content increased during frozen storage and that there was a simultaneous decrease in phospholipid content.

The lipid changes associated with frozen storage were subsequently studied in more detail using silicic acid chromatography and paper chromatography. Cod muscle lipids were separated into seven distinct components (Fig. 1), which by chemical and chromatographic analysis have been identified as follows:

Component I: esterified cholesterol and probably other sterol esters; also hydrocarbons, waxes and alcohols;

Component II: free fatty acids and triglycerides;

Component III: free cholesterol and other sterols;

Component IV: unidentified phospholipid (contains phosphorus and nitrogen but no serine, ethanolamine, inositol or choline);

Component V: phosphatidylethanolamine;

Component VI: mixture of phosphatidylserine and phosphatidylinositol;
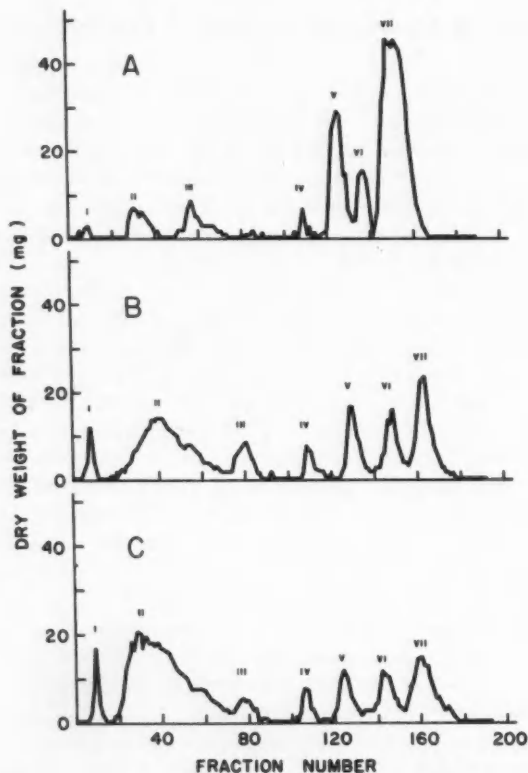
FIG. 1. Silicic acid chromatography of cod muscle lipids extracted with chloroform–methanol (Bligh and Dyer, 1959). Approximately 1 g lipid was applied to each column (50 g), followed by gradient elution with n-hexane→chloroform→methanol. Fractions of 10 ml each were collected. Curve A was obtained for lipids extracted from pre-rigor cod muscle (600 ml n-hexane and 500 ml each of chloroform and methanol used for elution); Curve B, cod muscle stored at 10°F for 7 weeks (600 ml of each solvent used for elution); Curve C, cod muscle stored at 10°F for 37 weeks (600 ml of each solvent used for elution).

Component VII: phosphatidylcholine and a much smaller amount of sphingomyelin.

The chromatograms indicate that hydrolysis of phosphatidylethanolamine and phosphatidylcholine was mainly responsible for the increase in free fatty acids in the frozen samples. Phosphatidylserine and phosphatidylinositol apparently were not affected.

It is noteworthy that the phospholipid components of the fresh cod sample (Curve A, Fig. 1) amounted to 83% of the total lipid, and also that the phosphatides containing serine, inositol and sphingosine were present in appreciable quantities.

This and more recent work will be amplified by experimental and quantitative data in a forthcoming publication.

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